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# INTRODUCTION

This report is presented in three sections: Progress Summary, Milestone Summary, and Analysis Data. The first section briefly covers progress made in the general order areas during the third quarter of 1962. The second section presents an Apollo program schedule comparison and a milestone status report, which includes projected third quarter milestone completion dates. The third section treats in detail areas of progress requiring greater explanation than that given in the Progress Summary and includes tables and illustrations to supplement the text.

# I. PROGRESS SUMMARY

## FLIGHT TECHNOLOGY

### WIND TUNNEL PROGRAM

Eighteen wind tunnel tests were conducted during the report period. These included ten static force tests, two dynamic stability tests, one transient pressure test, four aerodynamic loads tests, and one heat transfer test. Data were obtained for the command module alone and for the launch escape vehicle (command module with launch escape system) in the subsonic through hypervelocity range. Twelve pretest reports, 14 tabulated data reports, and 13 stress reports were published during this period.

The first command module hypervelocity force tests were completed with the 0.04-scale FS-4 model in the Arnold Engineering Development Center (AEDC) Hot Shot II facility and the 0.05-scale FS-8 model in the Cornell Aeronautical Laboratory (CAL) shock tunnel.

Subsonic tests of the 0.105-scale FS-2 model of the command module alone were completed in the NAAL and Trisonic wind tunnels. These data disclosed significant Reynolds number effects in the low subsonic regime.

Subsonic force tests of the 0.105-scale FS-9 model of the command module with the parachute cover removed were completed.

Pressure distributions on the entry vehicle in the transonic regime were obtained from tests of the 0.02-scale PS-1 model in the Ames 2- by 2-foot transonic wind tunnel.

Initial force tests of the C-1 launch vehicle were completed in the Ames Unitary Plan Wind Tunnel (UPWT). Data were obtained in the Mach number range 0.7 to 3.4.

Transient pressure measurements on the 0.02-scale PSTL-1 model were completed in the Ames 14-foot transonic wind tunnel. Effects of the launch escape system (LES) washer on vehicle buffet loads were investigated.

Heat transfer distributions were determined on the command module 0.045-scale H-2 model at Mach number 10 in the AEDC C tunnel.

Component loads were obtained for the launch escape vehicle in the Ames UPWT.

During the next report period, 24 wind tunnel tests will be conducted. Nine will be static force tests, five will be pressure tests, seven will be heat transfer tests, and three will be dynamic stability studies.

Fifteen pretest reports and 25 tabulated data reports are scheduled for publication during the next report period.

The 0.085-scale FSJ-1 model will be tested in the Langley 16-foot transonic tunnel to determine detailed effects of better simulation of escape motor jet exhaust impingement on command module force and pressure data.

Initial tests on the 0.080-scale SD-1 structural dynamics model in the Langley 16-foot transonic dynamics tunnel are to be completed.

Dynamic stability data will be obtained for the 0.045-scale FD-3 models of the launch escape vehicle and the entry vehicle in the AEDC hypersonic tunnels B and C at Mach numbers 8 and 10.

The 0.02-scale FSL-1 model of the complete Apollo-Saturn launch vehicle will be tested in AEDC tunnels A, B, and C and in the NAA Trisonic and Columbus division tunnels to obtain aerodynamic force data throughout the Mach number range 0.2 to 10.0.

Pressure distributions at hypervelocities on the entry and hypersonic abort vehicles will be obtained at Mach 20 in the AEDC hypervelocity tunnels F and Hot Shot II using the 0.040-scale PS-4 model.

Steady-state and transient pressure testing in the Mach number range 0.7 to 3.5 will be completed on the 0.055-scale PSTL-1 model of the Apollo-Saturn launch vehicle in the Ames unitary tunnels.

Heat transfer rates to the 0.050-scale H-4 model of the command module entry configuration will be determined at Mach number 15 in the CAL 48-inch shock tunnel.

## AERODYNAMICS

With the current center-of-gravity location, the command module lift-to-drag ratio during entry will be less than the required 0.50. Studies will continue to determine design modifications necessary to obtain the required performance characteristics.

Wind tunnel results indicate that a strong second-trim point exists in command module flight with the apex forward. The problem is aggravated by the reduction in center-of-gravity offset shown in current weight

statements. Design modifications, including the addition of external surfaces in the apex region, are under study.

Preliminary analyses of command module and launch escape vehicle dynamic stability tests were completed.

A computer program was written to perform calculations of the static aerodynamic characteristics of the launch escape vehicle as affected by escape motor operation.

Static pressure distributions for the command module, service module, and adapter were prepared for design loads analysis of the booster configuration at transonic and supersonic Mach numbers.

As a result of studies, modifications were made to improve the static stability characteristics of the launch escape vehicle. A flow separator was installed on the escape motor just forward of the rocket nozzle fairing.

Preliminary analysis of the subsonic static force data for the command module with the parachute cover removed was completed. The results show no significant differences with data obtained with complete command module.

During the next report period, command module configuration studies will continue to determine the design modifications necessary to restore the entry lift-to-drag capability and to minimize the effects of apex-forward trim.

Dynamic stability analyses will be continued to determine the effects of center-of-gravity offset on the damping derivatives for the command module and the launch escape vehicle. Additional studies will be conducted to determine the effects of the launch escape vehicle flow separator at high angles of attack. Analysis of the results obtained in free oscillation tests at Jet Propulsion Laboratory will be completed.

Studies to determine the effects of escape motor exhaust jets on the stability of the launch escape vehicle will continue. Checkout of the digital program to compute the static aerodynamic characteristics will be completed, and altitude and free-stream velocity effects will be calculated.

Air loads studies will be extended to include analysis of data obtained with the launch escape vehicle component loads model.

Analysis of the command module aerodynamic characteristics will be continued; altitude and scale effects will be determined.

A preliminary analysis report will be published presenting results of static pressure tests on the command module alone and the launch escape vehicle.

FLIGHT DYNAMICS

The design of a passive LES has been completed. Thrust levels, burning times, and alignment tolerances for the kicker rocket, the main motor, and the jettison motor have been defined. Optimum time for separation of the tower from the command module following abort has been determined.

A simulation study has been conducted to determine the fuel requirements and motor duty cycles during a manually controlled reentry. Use of either single or dual reaction system was considered using various maneuver ranges and entry angles.

A program that incorporates both wind tunnel and aerial drop testing of the recovery system has been released. Initial results from the aerial drop program are becoming available. This comprehensive program should determine predictive equations and demonstrate system performance.

The dynamics of separating the command module and service module from the booster have been studied for normal and abort conditions. Various techniques of providing the separation rates and distances and the means of providing ullage have been studied. It appears that the abort requirements are the most critical for system design purposes.

A preliminary analysis of the service module gimbal actuator requirement has been conducted. Initial required system characteristics have been determined using a midcourse velocity correction as the design condition. Results indicate that the present requirements for minimum accelerations and rates of deflection of the gimbal are higher than necessary and can be relaxed.

The service module propellant requirements for performing the various flight maneuvers have been determined for the lunar landing mission. Reaction control system (RCS) fuel requirements have been determined to provide vehicle damping throughout the entire flight and to perform the various dynamic maneuvers for each phase of flight including angular orientation, velocity corrections, ullage, separation, and docking.

A study of the attitude orientation requirement following the high-altitude atmospheric abort is being conducted, and a firm requirement has been established for providing artificial damping in the event that the

command module tumbles as a result of launch abort. The necessity of providing an attitude reorientation capability following damping of the body rates is being studied.

During the next report period, the LES will be further evaluated. Analysis of the effects of revised system weights and modified aerodynamic data on the system performance will be the primary objective. Performance of the LES in regard to booster dispersion following malfunctions during launch and the possibility of an explosion hazard will also be further explored.

A more complete analysis of the service propulsion system (SPS) gimbal actuator requirements will be initiated. Flexibility and slosh effects will be included in the system mathematical model. Design conditions other than the midcourse velocity correction will be studied to determine whether the requirement for these flight phases will modify the design criteria.

Service module and RCS propellant requirements will be reevaluated as the vehicle maneuvering requirements are more closely defined. Thrust levels will also be reexamined in light of the navigational sighting criteria and modified vehicle characteristics. The effect on propellant requirements by positioning the RCS at various distances above the service module will be studied.

An investigation of the docking maneuver will be conducted at the NAA Columbus facility to define more closely the control requirements during docking. This investigation will aid in designing mating mechanism.

Study of the high-altitude abort orientation requirements will be continued, and the ability of the pilot to perform the reorientation maneuver manually will be further investigated. The possible advantages of aerodynamics modification that will eliminate the apex forward trim condition will be analyzed. Further studies of reorientation requirements following lower-altitude abort will be conducted. Though tumbling would not occur at lower altitudes, it is indicated that this phase could prove to be extremely critical because it may not be within the control capability of the vehicle to reorient following abort.

The recovery system dynamic performance will be evaluated as aerial drop tests become available. Wind tunnel testing of the recovery system will be initiated, and correlation of the theoretical and test results using analytical techniques and computer simulation will begin.

Analytical studies and computer simulations of the back-up reentry energy management techniques will be conducted. Primary consideration will be given to system requirements and dynamic characteristics, ranging,

survival features, system complexity, and compatibility with the primary system.

## PERFORMANCE AND TRAJECTORIES

The service module design propellant capacity was established as 45,000 pounds.

Parametric studies were performed to determine the effect of weight, lift-to-drag ratios, entry velocities, density profiles, and deviations in density profiles on lunar mission entry corridors.

A terminal steering concept that can be used to control the flight path to a preselected site during the atmospheric phase of the entries was developed.

Preliminary trajectory information for most of the planned boilerplate and unmanned prototype flights was assembled and documented. These data present, in tabular form, trajectory parameters for each event from launch to end of flight.

NASA-recommended $\Delta V$'s were evaluated using NASA ground rules for the lunar landing mission employing lunar orbital rendezvous.

The lunar surface areas that can be reached any day of January 1969 were determined using the NASA $\Delta V$ capability without a safety margin.

A generalized study was made of circumlunar trajectories in a restricted three-body model.

The typical trajector for the Little Joe II maximum q abort test and the Little Joe II performance envelopes for the high-altitude and very high altitude abort tests were established.

The service module engine duty cycles were specified for the earth orbital, circumlunar, translunar abort, lunar orbit, and lunar landing missions.

Formulating, programming, and checkout of an elliptic orbit error analysis program were completed.

During the next report period, command module trim requirements will be determined to meet the entry and stability and control requirements.

Lunar mission flight envelopes and preliminary "guaranteed" impact footprints will be determined.

Safe entry criteria and preliminary back-up guidance requirements will be defined.

The study of transearth midcourse correction requirements will be completed, and the effects of making orbit determination measurements prior to injection will be included in the analysis.

Optimum lunar orbit altitude based on $\Delta V$, lunar orbit stability, lunar excursion module rendezvous concept, and abort considerations will be determined.

Desirable lighting restrictions for various trajectory events will be compiled, and the allowable launch periods that satisfy the restrictions for various months will be determined.

GOSS analyses of earth orbit and lunar flights will be continued to determine the effects of water recovery and parking orbit revolutions and to determine the optimum parking orbit altitude and maneuver sequence to maximize station overflying or minimize the required number of stations.

Typical trajectories will be generated incorporating earth oblateness, solar perturbations, lunar triaxiality, and lunar orbit eccentricity affects.

The design boost loads trajectories for the Saturn C-5 and the Little Joe II vehicles will be completed.

A trajectory analysis report, "Three-Dimensional Translunar Trajectories," will be published.

## AEROTHERMODYNAMICS

### Aeroheating Analysis

During the past report period, methods and techniques used in the prediction of aerodynamic heating rates were reviewed and evaluated.

Flow-field and heat-transfer data for the entry capsule model were analyzed and compared with theory.

New computing programs were written for the calculation of entry aerodynamic heating rates and for the prediction of heating caused by rocket exhaust plume impingement.

The equilibrium radiative heat transfer calculations were modified to use more accurate absorption coefficients for air.

The reduction and analysis of the command module RCS entry heating test data will be completed during the next report period.

Wind Tunnel Program

Wind tunnel heating tests of the entry and launch configurations were completed at AEDC.

The test program for obtaining convective heating rates on the face and afterbody of the command module was completed at Avco.

An 0.045-scale model of the launch configuration planned for the next AEDC tunnel tests was fabricated.

The entry heating tests of the command module RCS were initiated.

During the next report period, the following tests will be made: a 0.045-scale (7-inch diameter) model of the command module will be tested in the CAL 48-inch shock tunnel, a 0.045-scale model of the launch configuration will be tested in the AEDC B and C tunnels, and a 0.04-scale model of the command module will be tested in the AEDC hot-shot tunnel.

Launch Escape Subsystem

A thermal analysis of the thermal protection requirements of the launch escape motor flow separator was completed. A fiberglass insulation 0.2 inches thick will be required to prevent the face sheet of the flow separator from exceeding 600 F during boost heating.

Testing of the thermal protection material for the LES tower, scheduled for completion during the past quarter, will be accomplished during the next report period.

The LES tower impingement heating tests are scheduled to be completed during the next quarter. Subsequent tests may be required to provide an optimum weight design of thermal protection system for the tower. Further thermal studies of LES components are planned as design progresses.

Command Module

A plan for a heat shield qualification test program was completed. This program includes the consideration of orbital and supercircular reentry tests of the heat shield design prior to manned flights of the Apollo vehicle.

Arc-jet tests of ablation samples with various hole patterns and protuberances were completed. These tests have resulted in the establishment of preliminary design limitations for heat shield penetration of the umbilical connectors.

Temperature histories of the heat shield substructure at various locations were estimated for the overshoot entry trajectory.

During the next report period, additional predictions are planned of the temperature histories of the command module components during entry heating. Heat shield studies and arc-jet testing will continue during the next quarter.

Service Module

A parametric analysis of various honeycomb panel face thicknesses and core densities was made. This was done to determine temperature histories of the adapter at the base of the service module during the boost portion of the mission. The results indicated that for a maximum allowable temperature of 375 F with a honeycomb core density of 2 pounds per cubic foot any face thickness greater than 0.019 inches can be used, and that for a core density of 3 pounds per cubic foot the face thickness should be 0.017 inches or greater.

Boost heating studies of the service module structure and components are planned as design progresses.

## SPACE HEAT TRANSFER

Command Module

A thermal analysis was made of the command module aft equipment compartment and aft heat shield for all space mission phases. This investigation was based on the condition that the service module fuel tanks would be individually insulated. Under these conditions, it was found that the temperature of the aft heat shield stainless steel honeycomb went as low as -140 F, which exceeded the lower limit of -100 F established for this structure.

A second investigation, which is partially complete, considers insulating the interior shell of the service module rather than the individual fuel tanks. For this condition, it was found that the aft heat shield remained above 65 F during the translunar mission phase. It is anticipated that the temperature will not drop below 40 F for the entire space mission.

An analysis was made to determine the minimum expected surface temperature of the command module during a space mission that included

the lunar excursion module. Results indicate that a minimum surface temperature of -287 F can be expected if the apex of the command module is solar oriented and shielded from solar radiation by the lunar excursion module. If the composite structure cannot accommodate the low temperature, a method of vehicle orientation may be required by which the surface of the command module would experience periodic solar radiation in order to raise the temperature of the surface to an acceptable level.

The thermal analysis of the aft equipment compartment and heat shield during space flight with the interior of the service-module shell insulated will be continued.

A parametric study will be performed to determine heat gain or loss from the cabin during space flight.

The effect of roll periodicity and solar inclination on minimum surface temperatures will be determined.

Service Module

A parametric study to determine requirements for propellant thermal protection during space flight was completed. This study was made for

A study will be completed that will show weight savings resulting from designing the ECS for crew members.

Fire hazard studies of materials exposed to a 5-psia oxygen atmosphere will continue.

Test plans and instrumentation requirements will be prepared.

The computer programs for the suit circuit, cabin air circuit, and coolant loop will be updated as more detailed component performance data become available. The present steady-state programs will be investigated for modification into transient analyses. These programs will contribute to the continued evaluation of ECS performance.

Crew Support and Water Management

The computer program for the water management system will be updated as new data become available. This program will aid in the continued evaluation of system performance and requirements. A further analysis of the revised hot and cold potable water system will be made.

Performance analysis will be continued on the waste management system, and the recently revised schematic will be evaluated.

Unmanned Spacecraft Cooling Analysis

A basic instrumentation cooling system concept was established that will be suitable for pad abort, max q, early orbital, and possibly the high-altitude abort test vehicles (boilerplates 6, 12, 13, 21, 22, and 23). This system provides both ambient and coldplate cooling as required and has sufficient flexibility to permit the purchase of off-the-shelf components.

System analysis including coldplates has been completed sufficiently for system design to progress. More information is needed on boilerplates 16, 18, and 23 (later orbital and high-altitude abort) regarding the type of cooling required for each instrumentation package, the temperature and pressure limits, and the length of time the equipment will be required to operate during each mission.

During the next report period, design support will be provided to detail-design the cooling system for the pad abort, max q, and early orbital boilerplate vehicles.

Equipment Cooling Analysis and Test

The single coldplate computer program will be expanded to include the complete electronic cooling, coldplate network.
the condition when high vacuum insulation is placed on the inside of the service module shell and on the radial shear panels. Results indicate that a minimum of 0.1 inches of insulation is required to prevent freezing of the propellant.

A thermal analysis was made of the main engine propellant lines during the earth orbit, circumlunar, and lunar orbit mission phases. Results indicate that heating of the propellant lines would be required during earth orbital flights. Heating of the lines during circumlunar and lunar orbital flights will not be necessary if the total insulation thickness on the meteoroid shield and propellant line is greater than 1.50 inches.

An analysis of the main engine fuel injector plate indicated that a minimum heater capacity of 65 watts would be required to maintain a temperature above 40 F.

A thermal analysis was made of the cryogenic storage tanks during the translunar and lunar orbit mission phases. The maximum surface temperature of the tanks during these mission phases was determined to be 81 F.

During the next report period, the parametric study of propellant thermal protection requirements during space operations will be extended

to a three-dimensional analysis incorporating the latest service module design configuration.

Detailed component temperature studies will be continued for the translunar, lunar orbit, and transearth mission phases.

Refined analyses of component insulation or heater requirements are planned as design progresses.

## ENVIRONMENTAL CONTROL SUBSYSTEMS ANALYSIS

### Temperature and Atmospheric Composition Control

Computer programs were completed for the suit circuit, cabin air circuit, coolant loop, and water management system. These programs are being used for all mission phases to analyze and evaluate the ECS, monitor the ECS subcontractor, and evaluate design changes.

An analysis of the GSE used to service the ECS during prelaunch was started. No detailed results are available at this time.

Laboratory test programs on the honeycomb coldplate using the simulated electronic module are expected to be completed during the next period.

Interface conductance tests will be continued to find a practical material to provide satisfactory conductance under both pressurized and vacuum conditions.

Test and analyses will be continued on such passively cooled equipment as lights and display meters.

## POWER SUBSYSTEMS ANALYSIS

### Space Radiators

The electric power system (EPS) radiator was resized for the lunar orbit mission. A total of 48 square feet divided into six sections will meet requirements of the design case, the lunar orbit single module emergency condition.

The environmental control system (ECS) radiator was analyzed for performance in various locations during earth and lunar orbit using the radiator as designed for the lunar landing. This analysis resulted in a

series of curves showing glycol outlet temperature and total rejected heat versus angular position in orbit. A new study based on the lunar orbit mission was started for the radiator size.

Approval was obtained from NASA to test eight sample radiator coatings on the S-17 OSO (orbiting solar observatory) under actual space conditions. Sample coatings are being submitted by approximately 15 organizations for screening and testing prior to installation on the OSO.

Studies have begun to determine if the radiators can be relocated to avoid heating and contamination by the RCS plumes. The areas being investigated are the aft end and sides of the service module as far away as possible from the RCS nozzles.

During the next report period, the minimum size of the EPS radiator will be checked for conditions other than single module emergency in lunar orbit. If a significant reduction in size is possible, a study will be made of the supplemental cooling requirements and of the resultant shortening of the mission required for the single module emergency lunar orbit case.

The controllability of the ECS radiator will be checked for earth and lunar orbit conditions. This study will consist of checking the heat-rejection capacity and the glycol pressure drop in the separate radiator sections under various bypass conditions.

When the EPS and ECS radiators have been located in optimum positions and the preferred operating conditions have been established, a final analysis will be made to determine optimum design.

A program will be conducted to find or develop the most suitable radiator surface coating for the spacecraft.

Tests to determine the effects of RCS plume impingement on the space radiators and consequent heating will be combined with the RCS tests to be run at AEDC.

Supercritical Gas Storage Subsystem

The hydrogen vessel size was increased as a result of the mission change, and the oxygen vessel capacity was increased because of nitrogen system detection. Ullage was reduced on all tanks to minimize tank weight. This reduction was based on an optimization study relating ullage, ground stand-by time, pressure vessel weight, and insulation weight. Insulation thickness was slightly increased.

An analytical comparison was made between electrical heaters and an ethylene glycol-water solution to maintain constant tank pressure during gas withdrawal. The study indicated that electrical heating offered simplified control, improved reliability, and reduced weight. The electrical heating arrangement was adopted.

Analyses were made to determine GSE cryogenic line sizes, cool-down times, and fill times.

Studies of total heating requirements for the cryogenic vessels during the entire mission were completed. Transient analyses of pressure and temperature levels for abnormal flow conditions were begun.

During the next report period, the supercritical gas storage system configuration will be completed, and in-tank heat exchanger configurations will be determined.

A study of tank insulation sizing will be conducted, and studies of thermal diffusivity within the cryogenic fluids will be continued.

Equipment Cooling Analysis and Test

Calculated results from the present single coldplate computer program showed satisfactory agreement with the first experimental test coldplate. This computer program is being expanded to include the entire electronic cooling network.

Various interface materials were tested for conductance at both sea-level pressure and vacuum conditions. The only satisfactory materials tested have been grease-type compounds.

Coldplate redundancy studies were made of various system combinations. Reliability studies are in progress to determine the lightest possible system.

Several procedures for the initial pressurization of the cryogenic storage vessels were analyzed and compared.

Fuel Cell Subsystem

An analysis of the rapid cool-down requirements for the fuel cell module was completed. A rapid cool-down (from 500 F) was considered for the case of malfunction during the prelaunch or ground checkout phases. The purpose of this analysis was to minimize down time during replacement of the module.

Steady-state heat rejection during ground checkout of the EPS was considered both by the use of an auxiliary heat exchanger and by the use of space radiators and natural cooling. The analysis was completed and presented in parametric form.

During the next report period, the development of a computer program for determining the steady-state and transient temperature gradient across the electrode will be continued. An alalysis of thermodynamics control of the fuel cell system will be initiated.

PROPULSION SUBSYSTEMS ANALYSIS

An analysis of reentry heating effects on the Marquardt semiradiation-cooled command module RCS indicated that this design would not perform satisfactorily. Recommendations were made that an all-ablative type RCS engine be used for the command module.

The results of a SPS optimization study caused the design of the engine nozzle expansion ratio to be increased from 40:1 to 60:1. Significant spacecraft gross weight advantages were gained by this change.

A preliminary analysis of the various factors affecting the launch escape motor thrust vector alignment has shown the critical nature of various motor design parameters.

An analysis of the LES plume impingement loading on the tower structure was completed for one configuration. This study indicated that additional changes to the LES motor nozzle cant angle or the tower structure design are desirable to reduce impingement effects.

An investigation was conducted on the service module/S-IV stage separation characteristics. Two-dimensional water-table simulation tests of the fire-in-the-hole separation technique show that the size and location of the blow-out panels are critical parameters in the interstage design. A preliminary evaluation of other modes for stage separation indicates that the use of posigrade rockets offers significant advantages.

During the next report period, the parametric study of the command module RCS ablative engine will be integrated with parametric propellant system data.

Engine characteristics will be investigated, and engine specification requirements will be determined.

The study of the function of service module RCS engine materials, including molybdenum and molybdenum disilicide, under various environments will be completed.

Analyses will be continued of the RCS engine minimum-impulse characteristics as a function of pulse width.

A study of the obtainable specific impulse (frozen versus shifting equilibrium flow) in the RCS and SPS engine nozzles will be initiated.

Rocket plume impingement characteristics from the service module RCS will be defined for various offset distances from the surface and for various cant angles.

The parametric study of the relationship between the service module surface, RCS and service module, and the location of the service module radiators will be completed using the Marquardt plume profile and hyperbolic flow lines. This study will be refined as better techniques for determining plume shape become available.

An IBM program for predicting the RCS exhaust plume profile will be completed and evaluated. Correlation of the test results with analytical methods will permit better predictions of plume surface heating effects.

A three-phase service module RCS study at AEDC is being planned. Phase I will demonstrate altitude characteristics of cell J2A; Phase II will determine plume heating characteristics on a simulated service module surface; Phase III will demonstrate the firing characteristics of a full service module RCS system under hard-vacuum conditions. Instrumentation for use in the Phase II and Phase III tests at AEDC will be evaluated, and test plans will be completed.

A study of the effects of meteoroids on the RCS engine of the service module will be initiated.

The analysis of the LES plume boundaries will be continued using holograph techniques. Studies of the plume impingement on the LES tower structure as a function of altitude will be made.

The investigation of solid propellant motors for possible use as a posigrade service module/S-IV separation technique will be continued.

Heat transfer analyses of the Apollo solid propellant motors will be continued.

The study of the critical parameters affecting alignment of the launch escape motor thrust vector will be continued.

## PROPELLANT SUBSYSTEMS

### Service Module Main Engine

The analysis of the service module propellant system was updated to include the following system requirements:

1. Propellant tank capacity, 45,000 pounds
2. Service-propulsion-engine thrust, 21,900 pounds
3. $I_{sp}$, 319 seconds

Analysis methods have been refined to account for real-gas properties of helium and to include heat transfer from the storage bottle to the supply gas.

A trade-off study of different helium pressurization systems was made. This study was made to evaluate critical areas in each system, to compare weight, and to provide trade-off data for use in the selection of tank pressurization system.

At present, a fuel-to-low-pressure helium heat exchanger is recommended. Because bubbling helium into both fuel and both oxidizer tanks would provide improved performance, studies of bubbling systems will continue. A cryogenic system represents the greatest design risk.

During the next report period, a computer program will be used for detailed analyses of the various helium pressurization systems. These analyses will be augmented with more realistic heat transfer data and information pertaining to both launch and space environmental temperature considerations as these data become available.

A subroutine will be developed to calculate equilibrium temperature and pressure in the ullage. This computer program will be used for a detailed analysis of pressurization system performance during all missions and operating modes.

The study of pressurization-system configurations will continue to develop design trade-off data.

Systems analyses will be conducted to develop trade-off data for various propellant utilization (PU) valve and gaging system configurations.

An analog simulation will be formulated to ascertain the control characteristics of the various PU systems.

A pressure drop analysis was initiated on the SPS distribution system for the parallel propellant tank configuration with simultaneous feed. This system minimizes center of gravity during feed-out and may result in the propellant tanks having a lower operating pressure.

An analysis of the PU valve in the oxidizer feed-line of the service module main propulsion unit has been completed. The PU valve configuration was prescribed to consist of one automatic and one manual valve in parallel located in the oxidizer line. The manual valve was specified to have the capability of making a 2.0-percent correction for any failure mode of the automatic valve. To provide the 2.0-percent correction capability, the required pressure-drop range of the PU valve was determined to be 4.2 through 11.6 psi with a nominal operating value of 7.75 psi.

Analyses were conducted of the propellant line sizes required for the connecting lines between the propellant tanks and the engine interface of the service module main propulsion system. These analyses were based on the configuration of propellant tanks connected in series and the PU valve in the oxidizer line.

The line diameters were selected to be 2.0 inches inner diameter for the fuel line and 3.0 inches inner diameter for the oxidizer line. These line sizes are the same as the presently proposed engine line size at the engine interface. With these line sizes, the pressure drop in the oxidizer feed line, including the PU valve, is 11.3 psi. The fuel line will have to be equal to this to supply balanced pressure to the engine interface. A precision orifice yielding a $\Delta P$ of approximately 2.85 psi will be added to the fuel line to allow for manufacturing tolerance in each system. An optimization study confirmed that a 3-inch inner diameter oxidizer line and a 2-inch inner diameter fuel line are optimum line diameters from the standpoint of system weight.

## Command Module RCS

An analysis of the command module RCS propellant transfer line sizes showed that the propellant line sizes resulting in minimum system weight will have an excessive pressure drop. Therefore, the propellant line sizes are based on flow control considerations. Sizing has been completed for the command module RCS helium reservoirs and for the transfer lines of the helium pressurization systems.

During the next report period, studies will be conducted to enable more accurate determinations of the heat transferred to the helium reservoirs during reentry from various missions. From these determinations, a more sophisticated analysis of the helium requirements will be made.

The line sizes will be determined by IBM methods for the sections of each propellant transfer system. These programs are expected to be checked out and be in production during the next period.

Service Module RCS

An analysis was made of the service module RCS pressurization system to determine the helium line sizes.

The pressure surge (water hammer) in the service module RCS system was estimated by reducing the system to a simplified configuration. The surge pressures obtained are more conservative than the actual values.

An analysis was completed of the effect on system operation when a temperature difference of up to 20 F exists between the fuel and the oxidizer tanks. The system operation was affected only slightly by the temperature difference.

During the next report period, the RCS relief valve in the service module will be studied to determine the proper size for condition-of-failure in the open position of two regulators in series.

A computer program will be developed for more detailed pressure surge analysis of the service module RCS.

A program was initiated to simulate the transient and steady-state behavior of the propellant and engine systems of the service and command module using analog computers. Transient relationships such as helium-regulator transfer functions and general water hammer wave equations are available and are being applied to specific propellant system configurations.

Development of the analytical equations describing the transient and steady-state behavior of the Apollo propellant systems will be continued for the analog study during the next report period.

## GROUND SUPPORT EQUIPMENT

GSE Helium Transfer Facilities

Investigation shows that a cryogenic heat exchanger will be required in the SPS helium transfer equipment. The heat exchanger is needed to precool the helium to a temperature of less than -200 F before transfer to the service module storage vessel, to achieve the desired loaded condition of 70 F at 4500 psia.

The theromodynamic processes occurring during transfer of helium from the ground-storage facilities to the service module are being analyzed. Results of this study will be used for correct sizing of the ground support servicing equipment.

Transient temperature of the service module storage vessel wall during helium loading will be predicted during the next report period.

GSE Propellant Loading Facilities

A study has been initiated to determine the required flow rates and pressures at the GSE vehicle interfaces for the loading of propellants in the service and command modules.

GSE Checkout Facilities for Engine Systems and Propellant Distribution Subsystems.

Checkout procedures are being developed for the evaluation of rocket engine and propellant distribution systems on the command and service modules during both simulated and actual engine firing conditions.

# INTEGRATION AND SUBSYSTEM ANALYSIS

## SUBSYSTEM ANALYSIS

The boilerplate 9 support analysis was completed and reproduced for distribution.

The boilerplate 19 support analysis was advanced to 90 percent of completion.

The service module propulsion system trainer support analysis and related GSE was completed and distributed on 5 September 1962.

The service module reaction control trainer preliminary support analysis was published and distributed this quarter.

The service module environmental control system initial analysis was brought to 90 percent completion.

The GSE utilization document was prepared and is undergoing engineering coordination.

GSE serialization and location document forms have been approved and are in production.

The GSE master phasing schedule bar chart for installation, hookup, and checkout at test sites for all boilerplates and airframes was completed.

The Apollo support plan was delivered 30 September 1962.

The Apollo maintenance concept was delivered.

Integration and systems analyses will be continued.

Analyses to provide GSE and spares support for all scheduled tests and test articles will be conducted commensurate with program requirements and design identification.

[redacted]

## CONFIGURATION CONTROL

### Combined Systems Schematic

The estimated completion date of the integrated systems schematic for boilerplate 6 was revised due to the redesign of the launch escape system (LES).

The sequencer schematic of the earth landing system (ELS) was received but must be integrated with the LES sequencer.

### Inboard Profiles

The inboard profiles on the command module, service module and boilerplates are in work. A master inboard profile for spacecraft assemblies was begun. The drawing for boilerplate 3 was completed. The command module drawings reflect the latest changes for the lunar excursion module. The service module change from 140 inches to 155 inches has been incorporated into the drawings.

### Systems Perspectives

The drawing configuration arrangement for boilerplate 1 was released.

### Configuration Control

The detailed hardware and associated GSE parts lists defining the configuration of boilerplates 1, 3, and 19 were completed and released. A complete reissue of this list for boilerplate 1 is in work.

All work on the detailed parts lists for the LES has been stopped pending redesign of this system.

Concepts and philosophies are being formulated for spares control configuration.

### Engineering Change Control Procedures

Engineering change control procedures were formulated reflecting current tentative agreements with NASA regarding response times for specific phases of a given change. S&ID interface working arrangements are being coordinated in order to initiate formalized procedures for the initiation, coordination, negotiation, and implementation of engineering changes. Documentation of engineering changes reflecting NASA redirection was begun.

## TEST INTEGRATION

### Measurement List

The operational measurement list, including displays and in-flight test system requirements for airframe 011, was established. The list of parameters and the format established will form the basis of all lists for all vehicles. This determines the size of the pulse code modulation (PCM) system.

### Standardized Numbering System

A standardized numbering system for all parameters and vehicles has been devised in conjunction with the measurement list determination. A computer program was written and debugged. Initial entry and printout of airframe 011 measurement list were accomplished.

### Propulsion System Test Plan

Preliminary engineering test requirements for airframe 011 were written. Measurement requirements were resolved and listed. Initial entry of the list into the automatic storage and handling system was completed.

### Test Requirements

Initial measurement requirements for pad abort boilerplates were issued. Plans will include determination of the adverse affects of ionizing space radiation and meteoroid impingement on both nozzle materials and coatings.

Specific plans include a continuation of screening new space lubrication concepts, conducting of applicability studies, and determination of whether or not newly developed systems are compatible with Apollo requirements. Tests will be conducted to determine both attributes and shortcomings of new space lubricants or lubrication systems.

In tests requiring precise space pressure simulation, $10^{-12}$ millimeters of mercury will be considered. Studies of the Ranger and Mariner flights will be made during the next period to determine if any lubrication techniques used can be adapted to the Apollo program.

A test program to determine design data for 18 Ni-9Co-5Mo maraging steel (parent metal and weldment) will be monitored.

Complex 39

The umbilical tower swing arm study report for complex 39 was completed. A report summarizing spacecraft systems prelaunch test requirements for complex 39 was transmitted to NASA.

Boilerplate 6

Integrated systems checkout requirements for boilerplate 6 were released. A digital computer program was developed to evaluate the operation of the launch escape sequencer for boilerplate 6.

Measurement Lists

The measurement lists for boilerplates 6, 12, 13, 16, 15, 18, 21, 22 and 23 were issued for NASA approval.

GSE Umbilical List

The GSE umbilical list for boilerplates 6, 12, 21, 22, and 23 was completed.

Telemetry Monitor Points

A revised list of telemetry monitor points for explosive bridge wire (EBW) voltages and sequence of events on all abort boilerplates was compiled.

Checkout Requirements

Checkout requirements for navigation and guidance system, stabilization control system (SCS), and RCS at the launch pad were established.

Primary attention will be given to the analysis of the ability of the Apollo guidance computer to provide interface signals during integrated checkout.

Electrical Phasing Check

An electrical phasing check was initiated to check navigation and guidance, SCS, RCS, and service propulsion system (SPS) as an integrated guidance and control system.

## SYSTEMS INTEGRATION

### Grounding and Bonding Criteria

The grounding and bonding criteria specifications were developed and forwarded to NASA.

Better bonding methods will be developed to eliminate the probability of bond failure between the panel and grip attachment areas. Subsequent to developing of adequate bonding methods, the remaining flat René 41 honeycomb sandwich panels will be formed into structural segments of the Apollo structural shell afterbody. These segments will be carefully measured for conformance with dimensional requirements, and will be tested for mechanical properties. If necessary, specimens will be subjected to thermal shock tests.

### Electromagnetic Interference

The preliminary document on general requirements for Apollo electromagnetic compatibility testing and shielded enclosure was released. This document outlines the electromagnetic compatibility test plan for systems and subsystems and electromagnetic shielded enclosure requirements for building 6-A.

The revised electromagnetic interference control specification for the Apollo space systems was released.

General electromagnetic interference control criteria for building 6-A facility electrical and electronic equipment were released. These criteria outline general requirements for providing electromagnetic interference control on facility-installed electrical and electronic equipment.

Electromagnetic interference control criteria for the pad abort boilerplates and Little Joe II launch facilities at WSMR are being established.

Interface analysis will commence on the instrumentation system of boilerplate 12.

## PROJECT REQUIREMENTS

### Summary Definitions and Objective Documents

The summary definitions and objectives document was revised. A subsequent revision was made to this document in accordance with redirection to the lunar orbital rendezvous concept without lunar excursion module

integration and to a revised master phasing schedule. Summary definitions and objectives were prepared for all but ten items of GSE listed on the hardware utilization list and for all trainers. Detailed definitions and objectives for boilerplates 1 and 2 were released.

Specifications

An Apollo ground operations requirements specification incorporating all ground operations requirements is being prepared. This specification will complement the mission and spacecraft requirements documents.

Apollo mission requirements, Apollo spacecraft requirements, and Apollo ground operations requirements were prepared to replace the following specifications:

1. Preliminary spacecraft performance
2. Preliminary command module performance and interface
3. Preliminary service module performance and interface
4. Adapter module performance and interface
5. Preliminary lunar landing module performance and interface
6. Apollo ground support equipment
7. Ground support equipment performance and interface

The following Apollo interface specifications are being prepared:

1. Navigation and guidance system
2. Research and development flight instrumentation
3. Scientific instrumentation
4. NASA-furnished crew equipment
5. Non-S&ID ground support equipment
6. Ground operational support equipment

7. Launch vehicles

8. Saturn

9. Little Joe II

A complete set of master PERT charts was reviewed to insure compatibility.

During the next period, preparation of material and process finish identification and procurement specifications will be completed. Analysis of the effects of meteoroid penetration of alumino-silicate glass as well as necessary tests are planned. Materials and methods for sealing the windows will be investigated. Possible materials such as fused silica and transparent alumina (synthetic sapphire sintered or cut from large bule) for transparent outer shell windows are to be investigated. Structural and thermal shock tests of the window materials for the pressurized shell will be started.

Lunar Landing Mission Time Line

An operations analysis of the lunar landing mission and related sub-missions time-line was prepared. This report is currently being revised.

Contingency Analysis

A contingency analysis was completed of lunar landing mission operations and abort sequences.

System Operations Analysis

An analysis of SCS, RCS, navigation and guidance, and communications systems operations was accomplished.

Investigations are planned using a three-body mathematical model of the heat shield - command module couch system. This is expected to provide a more representative analysis.

Equations were written, and a digital program is being prepared, for the analysis of an earth landing of the command module.

Electrical Power Requirements

A functions and operations analysis was performed to prepare an electrical power loads profile for a 14-day lunar excursion module mission.

[redacted]

Prequalification Drop Test Program

A feasibility study was initiated concerning the use of helicopters and/or balloons for the earth recovery system prequalification drop test program.

Universal Spacecraft

Configuration studies were conducted to evaluate selected universal spacecraft designs.

Lunar Landing Mission

Generalized optimization studies to accomplish the lunar landing mission by earth orbital rendezvous and lunar orbital rendezvous were conducted to determine the most efficient program to accomplish the lunar landing mission within present booster limitations.

Earth Orbital Rendezvous

An earth orbital rendezvous study was published as a summary of all previously conducted studies to provide a basis from which to start more detailed earth orbital rendezvous studies.

Spacecraft Adapter

A brief optimization study of the spacecraft adapters for Little Joe II, C-1, C-1B, and C-5 was undertaken to avoid design duplication in this area.

Lunar Excursion Module Interface

A preliminary lunar excursion module interface study was conducted; the resulting specification is being completed.

Adapter Buffet Loads

An investigation of the buffet loads of the command module adapter was undertaken, and resultant changes are being incorporated into the design.

Maximum q Abort Tests

Study of a method to initiate abort for the maximum q abort tests was requested.

Electrical Initiation Devices

Trade-off study of the electrical initiation devices (EBW versus hot wire) was coordinated and design philosophy transmitted to Apollo engineering.

Studies will be conducted on whether the sequencers and pyrotechnics can be checked out after final assembly in the arming area.

Safety Criteria

Tankage design criteria will be altered to conform to the safety factor criteria established.

Cold Welding

Analysis of cold welding will be performed, and requirements will be established regarding the scope of basic research or development in the area of cold welding.

Plans

Plans now call for the following items:

1. Analysis of the results of thermal shock tests already completed and modification of test techniques in an attempt to develop a true 'go no-go' thermal shock test method.

2. Continuation of thermal shock testing of metal honeycomb sandwich specimens made from various all-welded and brazed superalloy materials.

3. Evaluation of brazing alloys in combination with cure and face elements evaluated with respect to their ability to withstand thermal shock test conditions.

4. Analysis and correlation of overall thermal shock test results and determination of the possibility of predicting the strength and quality of a sandwich based upon thermal shock test evidence.

The following tasks are planned for the next period:

1. Revision and development of design criteria in all areas.

2. Maintenance of LES loads. The LES configuration and concept is not firm. Modify existing IBM program as necessary.

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3. Maintenance and development of boost loads for Saturn, Little Joe II, and Nova.

4. Development of lift-off and shut-down transient loads.

5. Maintenance of earth landing loads as weight, configuration, and concepts become firm.

6. Development of docking loads.

7. Maintenance of entry loads.

8. Support of configuration and concept studies.

## PACKAGING AND TRANSPORT SYSTEMS ENGINEERING

Analyses were conducted to determine the optimum transport modes for shipping boilerplate modules and spacecraft modules.

The following studies were covered in the Apollo packaging and transport plan.

Packaging, handling, and transport modes
Routes
Costs
Reliability
Scheduling requirements for GSE handling development
Availability of transport vehicles
Transit times

The packaging and transport plan established air transport by C-133B aircraft as the primary transport mode for shipment of the spacecraft command module. As a result of clearance of clearance problems (3/4 inch or less) between the C-133B aircraft structure and the service module, air transport for the service module is not considered safe. Truck transport was established as the primary transport mode for the service module and adapter unless a larger aircraft (a modified C-133B) becomes available.

Packaging concepts and design studies for shipment of formed honeycomb panels and honeycomb structure will be completed.

The command module recovery study will be continued.

# RELIABILITY

## COMMAND MODULE AIR LOCK

A reliability trade-off study was performed concerning the retention or elimination of the command module air lock. Relocation of the air lock to a position directly inside the main hatch should be considered. This arrangement would eliminate one large opening in the command module roof, simplify the structure in that area, and improve reliability. It would also eliminate the problem of sealing an opening 30 inches in diameter, simplify the nose cone and configuration, and reduce gas leakage.

## RELIABILITY ANALYSIS MACHINE PROGRAM

A Monte Carlo computer program for the analysis of spacecraft reliability has been completed and checked out. Work continues to include mission aborts and therefore allow the computation of crew survival statistics. The influences of on-board maintenance will also be included in this program.

## LAUNCH ESCAPE SUBSYSTEMS

A reliability apportionment was started to reflect the addition of a kicker rocket for the launch escape system (LES). Preliminary estimates require an increase in the reliability of the launch escape motor, with no change in the jettison motor reliability requirement. An ignition failure is the only remaining major failure mode which could be deleterious to crew safety. Redundant exploding bridge wire units assure a low probability of occurrence.

The program was revised to include sophisticated techniques for the handling of alternate modes of operation.

## FIELD TEST OPERATIONS RELIABILITY SUPPORT

Organizational and implementation plans for reliability engineering support to field test operations were prepared. Definitions of reliability organizations, functions, and personnel assignments were included.

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# INSTRUMENTATION

## CONTROLS AND DISPLAYS

A backup entry display breadboard incorporating a g-versus-time display was constructed.

A study is continuing for the purpose of evaluating the integration of time sharing instrument displays.

## MAIN DISPLAY CONSOLE

The first breadboard and mock-up of the main display console was constructed.

Studies are in progress on possible rearrangements of the electronic equipment located in the lower equipment bay.

Analysis of all electronic systems is under way to predict radiation and susceptibility levels. This information will effect an early correction of possible electromagnetic interference problems.

The current designs of main display console instruments will be mechanized.

The basic procurement specification is ready and will be released upon approval by NASA.

Environmental vibration and dielectric tests of connectors will be conducted during the next period.

Vibration and environmental tests of the locking devices for the modules in the lower equipment bay will be conducted during the next period.

# TRAINING AND SIMULATION

## SUBSYSTEMS TRAINER

Specific decisions as to what training is to be provided, who is to be trained, and who is to do the training have not been made to date by NASA. This information is vitally needed for incorporation into the training plan and for manufacturing scheduling.

## SIMULATION STUDIES

The "Apollo Simulation Studies Summary" was issued. This document is a master phasing plan for Apollo engineering simulation studies and outlines objectives, schedule requirements, and definitions for each study, computer evaluator and simulator usage requirements, and other peripheral equipment needs.

The Apollo simulation studies summary report is to be completely revised to reflect the program lunar excursion module redirection and upgraded technical requirements. The report will be issued as a formal S&ID document.

Simulation study activity will proceed in an accelerated program contingent upon computer and engineering evaluator availability. To optimize certain phases of simulation activity, four large studies will be undertaken covering flight phases 2.0 (entry), 3.0 (boost and separation), 4.0 (lunar operations), and 6.0 (orbital and space mechanics). Studies for other flight phases and supplemental effort will also be conducted.

The revision outlines the S&ID aspects of the simulation program based upon the lunar excursion module concept. Detailed definitions of each study however require reevaluation.

## DIGITAL MODULES AND CONVERSION EQUIPMENT

A survey is being conducted on commercially available digital modules, digital patchboard systems, digital-to-analog conversion equipment, and analog-to-digital conversion equipment. An investigation of printed circuits and card processing capabilities is in progress.

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## SPECIAL PURPOSE DIGITAL EQUIPMENT

A study to determine the requirements for a special purpose digital system employing patch panel techniques was initiated.

## AUTOMATIC CHECKOUT

Systems study and analysis were started to define automatic checkout equipment requirements for the over-all simulation program.

## APOLLO TRAINING PLAN

Revision of SID 62-162 is near completion and is scheduled for publication during the next report period. The revised training plan will reflect the requirements for preparation and conduct of effective training on Apollo spacecraft and associated GSE for the flight crew, flight controllers, and preflight personnel.

## APOLLO FAMILIARIZATION COURSE

Preparation for the familiarization course has been completed. The course has been conducted once for S&ID management and once for local NASA personnel.

# SPACECRAFT TEST OPERATIONS - DOWNEY

## HOUSE SPACECRAFT AND TEST PREPARATION AREA

The acoustic and vibration testing portion of the environmental proof program was incorporated in the test program of house spacecraft 2.

The detail test planning will be initiated for building 6A GSE installation and checkout and for boilerplate 14 (fuel cell system) installation and checkout during the next period.

## ENVIRONMENTAL SPACECRAFT TEST PROGRAM

Major reprogramming of the environmental proof tests was accomplished in conjunction with the over-all program rescheduling. To enable completion of all environmental proof tests associated with earth orbital flights prior to actual manned flights, the environmental vibration and acoustic tests were reprogrammed for accomplishment on AFRM 006. Environmental chamber tests will be accomplished on AFRM 008.

Coordination of test requirements, scheduling, support requirements, and GSE requirements was continued toward initiation of detailed test plans.

During the next report period, the major effort will be the formulation of a preliminary detailed environmental proof test program based on design and support requirements. A review of these requirements and plans will be conducted with NASA and AEDC personnel to align test requirements and chamber capability.

## APOLLO-SATURN TEST PROGRAM

The Program Requirements Document for AMR is approximately 85 percent complete. This issue will be submitted to NASA and will define the activities for boilerplate 13, 15, 16, 18, and AFRM 010.

During this report period, meetings were held with NASA-POD to finalize the AMR vehicle flow chart. Many of the major items have been agreed upon by NASA-POD and S&ID. A few minor items remain to be resolved.

The various time durations, checkout, and preparatory tests to be performed at AMR for the instrumentation systems have been determined and are now being reviewed.

The detail test plan for boilerplate 15 will be prepared and should be completed during the latter part of next period.

The R & D instrumentation systems for AMR flight of the boilerplates will be reviewed in detail, and the display and control parameters will be coordinated and established. Time durations for the various system operations will be studied and determined for operational instrumentation systems.

## SERVICE PROPULSION TEST PROGRAM

The planned spacecraft AFRM 001 altitude chamber firing program was deleted. A service propulsion test fixture will be provided to Aerojet-General for the rocket engine qualification program at AEDC. This qualification program will replace the altitude chamber firing program previously scheduled for this spacecraft.

The propulsion test facilities design criteria were reviewed by Apollo Test and Operations. Changes resulting from this review were relocation of the remote command module station to a position near the firing stands. This was done to reduce instrumentation, to control wire length and to permit command module reaction control system firing. Another change was the addition of a propellant conditioner capable of providing one complete spacecraft servicing of propellants within the temperature range of 40 F to 140 F.

During the next report period, the preliminary detail test plan will be completed for incorporation in Volume III of SID 62-109. Facilities, instrumentation, and support planning will be monitored as a parallel effort to the detail test planning.

## ABORT TEST PROGRAM

The PERT networks have been developed for all mission abort test vehicles.

Modification requirements for the rework of the WSMR-ALA 3 service tower have been established through coordination with NASA, General Dynamics/Convair, and WSMR personnel.

The mission test directives for the mission abort tests will be completed and forwarded to NASA during the next report period. These

documents will be used by NASA in the preparation of the MSC test mission directives for the WSMR operations.

## TEST PROGRAM COORDINATION

Apollo test and operations test program requirements for AMR have been completed and submitted for inclusion in the GFP/GFAE Requirements for Project Apollo Spacecraft Development Document (SID 61-299-2) and in the AFMTC Program Requirements Document. Apollo Test and Operations Mission Abort Test Program Test Support Requirements Document (SID 62-972) has been published. The GOSS Performance Specification (SID 62-1005) was reviewed and revised. Information concerning GOSS operations was provided for inclusion in the Ground Support Specification (SID 62-700-3).

During the next report period, the GOSS personnel will participate in the Mercury MA-8 Mission as observers for indoctrination and training.

Apollo Test and Operations test support requirements are being prepared for the following documents:

1. Apollo Test and Operations House Spacecraft/Test Preparation Program Test Support Requirements Document (SID 62-974).

2. Apollo Test and Operations Service Propulsion Development Program Test Support Requirements Document (SID 62-973).

3. Apollo Test and Operations Environmental Proof Test Program Test Support Requirements Document (SID 62-975).

## DATA ENGINEERING

Computer programs have been initiated and are undergoing checkout for automatic processing of calibration data and preparation of the master measurement list.

The parachute development drop test program has been initiated and seven tests have been accomplished to date. Test measurement data have been acquired, reduced, and distributed on the last three drop tests.

During the next report period, computer programs will be initiated for automatic reduction and evaluation of the telemetry data.

Effort will be continued in the support of the parachute development test program.

The requirements for the data acquisition system for the propulsion test at WSMR have been submitted and coordinated with Apollo facilities. The resulting specification will be submitted to NASA for approval and procurement.

During the next report period primary effort will be to review the general test concept with NASA after NASA review of the reissued General Test Plan (SID 62-109) dated 30 September 1962.

# DOCUMENTATION

The following S&ID documents relevant to the Apollo program were published during July, August, and September.

Qualification Status List, SID 62-784
Project Apollo Still Photos Submittal No. 5, SID 62-566-5
Scene List and Background Material for Project Apollo Submittal No. 2, SID 62-367-2
Apollo Quarterly Progress Report, SID 62-400-2
Monthly Weight and Balance Report, SID 62-99-6
GOSS Performance and Interface Specifications, SID 62-76
Monthly Failure Summaries (Letter 62MA-7299, dated 9 July 1962, forwarded to announce no failures at this time), SID 62-822
Drawing List, SID 62-384-8
Pretest Report for Transient Pressure Tests of the Apollo (PSTL-1) Model in Ames Unitary Wind Tunnels, SID 62-799
Pretest Report for Static Pressure Tests of the Apollo (PSTL-1) Model in Ames Unitary Wind Tunnels, SID 62-809
Pretest Report for the 0.055-Scale Apollo Pressure Model (PSTL-1) in NAA Trisonic Wind Tunnel, SID 62-745
Apollo Second Quarterly Report, SID 62-400-2 (Sent to B. Pratt by request of C. C. Johnson)
Scene List and Background Material for Project Apollo Submittal No. 3, SID 62-367-3
Project Apollo Still Photos Submittal No. 6, SID 62-566-3
Apollo Program Schedule Data, SID 62-916
Pretest Report for the 0.05-Scale Apollo Pressure Model PS-5 in the Cornell Aeronautical Laboratory Hypersonic Shock Tunnel, SID 62-900
Pretest Report for the 0.05-Scale Apollo Pressure Model PS-5 in the Cornell Aeronautical Laboratory Hypersonic Shock Tunnel, SID 62-899
Scene and Background Material for Project Apollo Submittal No. 4, SID 62-367-4
Scene and Background Material for Project Apollo Submittal No. 5, SID 62-367-5
Drawing List, SID 62-384-9
Project Apollo Still Photos Submittal No. 6-A, SID 62-566-6A

Test and Module Information for Wind Tunnel Tests of an 0.02-Scale Force Model (FSL-1) of the Apollo in the AEDC VKF Wind Tunnels "A," "B," and "C," SID 62-806

Test and Model Information for Wind Tunnel Tests of an 0.02-Scale Force Model (FSL-1) of the Apollo in Ames Wind Tunnels SID 62-

Data Report for Apollo PS-4 Model in the AEDC Hotshot II Wind Tunnel, SID 62-930

Summary of Earth Orbital Rendezvous Studies, SID 62-834-1

Pretest Report for 9.08-Scale Apollo Structural Dynamics Model (SD-1) in the NASA Langley Transonic Dynamics Wind Tunnel, SID 62-841

Apollo Mission Specification, SID 62-700-1

Apollo Spacecraft Specification, SID 62-700-2

Pretest Report for the 0.05-Scale Apollo Force Model in Ames Unitary Plan Wind Tunnel, SID 62-1007

Apollo Drawing List, SID 62-384-11

Tabular Data Report for Apollo Model (FS-1) Wind Tunnel Test SAL-199), SID 62-343

Data Report for Simulated Jet Plumes on the Apollo Model (FS-1) Wind Tunnel Test (SAL 1208), SID 62-1056

Apollo Mission Analysis, SID 62-379

Apollo Still Photographs, SID 62-566-9

Data Report for Langley Unitary Plan Wind Tunnel Tests (Project 374) of Apollo Model (FD-2), SID 62-1074

Data Report for Langley TPT Wind Tunnel Tests (Project 233) of Apollo Model (FD-2), SID 62-1065

Data Report for NAA Shock Tunnel Tests (ST-4) of Apollo Command Module Models H-6 and PS-6, SID 62-1072

Data Report for Apollo Model (FS-2) in Ames Unitary Plan Wind Tunnel, SID 62-1063

Apollo Navigation and Trajectory Control Trainer, SID 62-1091

Data Report for Wind Tunnel Tests of Apollo Model FS-4 in the AEDC Hotshot II Wind Tunnel, SID 62-977

Apollo Monthly Progress Report, SID 62-300-5

Monthly Weight and Balance Report, SID 62-99-7

Drawing List, SID 62-384-10

Project Apollo Still Photograph Submittal No. 7, SID 62-566-7

Boilerplate 25 (Command Module) for Water Recovery Procedures and Handling Equipment Development, SID 62-995

Qualification-Reliability Test Plan, SID 62-204

Design Criteria Handbook (Spacecraft), SID 62-431-1

Data Report for Apollo Force Model (FS-2) in NAA Trisonic Tunnel (TWT 74), SID 62-627

Test and Model Information for Wind Tunnel Tests of an 0.105-Scale Force Model (FS-2) of the Apollo in Ames Unitary Plan Wind Tunnels, SID 62-104

Data Report for Apollo Model (FS-2) in Ames Unitary Plan Wind Tunnels, SID 62-778
Apollo Still Photos, SID 62-566-8
Quality Control Plan, SID 62-154
Apollo Motion Picture Documentation Submittal No. 6, SID 62-367-6
Radiation Shielding Status Report, SID 62-821
Structural Analysis of the 0.055-Scale Apollo Dynamic Stability Model (FD-2), SID 62-103
Structural Analysis of the 0.02-Scale FSL-1 Model TWT Wind Tunnel Test NAS9-150, SID 62-673-1
Data Report for Apollo Model, FS-3, Wind Tunnel Tests in the A Tunnel of the AEDC Vonitarman Gas Dynamics Facility, SID 62-1057
Apollo Maintenance Concept, SID 62-702
Data Report for Apollo Model (FS-1) Wind Tunnel Test Ames 2 x 2 - 396, SID 62-1027
Drawing List, SID 62-384-12
Investigation of Increasing the Base Diameter of the Service Module, SID 62-997
Data Report for Static Pressure Tests of the Apollo PSTL-1 Model in NAA Trisonic Wind Tunnel (TWT - 77), SID 62-929
Pretest Report for the 0.085-Scale Apollo Force Model FSJ-1 Wind Tunnel Tests in the NASA Langley Research Center, SID 62-876
Structural Analysis of the 0.045-Scale Apollo Force and Pressure Model (FS-3 and PS-3), SID 62-777
Structural Analysis of the 0.045-Scale Apollo Heat Transfer Model (H-2), SID 62-616
Structural Analysis of the 0.055-Scale Transient Pressure Model (PSTL-1), SID 62-422
Data Report for Wind Tunnel Tests of Apollo Model FS-4 in the AEDC Hotshot II, SID 62-977
Structural Analysis of the 0.020-Scale Apollo Heat Transfer Model (H-1), SID 62-330
Structural Analysis of the Apollo 0.040-Scale Wind Tunnel Model, SID 62-331
Data Report for Apollo Models FS-1 and FS-7 Wind Tunnel Test (SPL - 20 - 495), SID 62-547
Apollo Motion Picture Documentation Submittal No. 7 Background Information and Scene Descriptions, SID 62-367-7
Structural Analysis of the 0.02-Scale Apollo Wind Tunnel Models (FS-1 and PS-1), SID 62-251
Structural Analysis of the 0.030-Scale Apollo Dynamic Stability Model (FD-1), SID 62-388
Monthly Progress Report, SID 62-300-6

Monthly Weight and Balance Report, SID 62-99-8
Monthly Failure Summaries, SID 62-882
Drawing List, SID 62-384-12
Drawing List, SID 62-384-13
Data Report for Apollo Model FS-Wind Tunnel Test (SAL - 1204), SID 62-753
Quarterly Reliability Status Report, SID 62-557-2
Materials Report, SID 62-823

Support manuals were realigned to support flight rated systems of boilerplates and GSE as recommended to NASA in SID 62-600.

NASA Support Manual General Style and Quality Requirements (SID 62-98) was revised to provide improvement changes incorporating samples of title page, support manual numbering system, and quality assurance forms for verification and engineering review. Subcontractors and suppliers will be required to adhere to the revised standards, and SID 62-600 will be included as an appendix to Apollo Support Plan (SID 62-702-1).

SID 62-695, Apollo Logistics Support for Tulsa Facility, was approved and published. Specific support manual requirements for Tulsa were identified and incorporated in the Statement of Work, Tulsa.

The eight motion picture documentation submittals for this quarter covered the following subjects:

Material Tensile Testing
Ablative Material Heat Shield Radiant Heat Test
Command Module Wooden Mock-Up Fabrication
Command Module Wind Tunnel Force Tests (0.02-Scale)
Plastic Master Model Tooling of Command Module, Service Module, and Adapter
Plastic Master Model of Command Module
Apollo Mock-Up Fabrication Progress
Handling and Transportation of Command Module Boilerplate Mock-Up
Apollo Life Systems Simulator
Hypersonic Dynamic Tests at JPL Wind Tunnel on 0.02-Scale of Command Module
Boilerplate 25 Water Impact and Flotation Tests
Parachute Drop Tests at El Centro

# PROGRAM MANAGEMENT

## PERT

During this report period, PERT Systems developed two complete sets of general-order networks and a supporting master network. These developments were based on major changes in the master phasing plan. NASA agreed to accept master network reporting on a trial basis during September and October, but rejected this concept late in September in favor of general-order networks.

During the next period, the reporting system from the subcontractors to S&ID and from S&ID to NASA should be operating satisfactorily.

Management networks have been approved for all subcontractors except Collins Radio and Minneapolis-Honeywell. Acceptance of these two networks is anticipated. Bi-weekly, TWX computer and narrative reports are being received and used as a basis for up-dating networks and determining subcontractor status. Effort to increase visibility will be directed towards subcontractors' networks.

Key dates (latest, estimated, scheduled, and actual) will be posted to the individual general order networks and the master network from the IBM tabulation. Changes to the networks will be reported weekly to the Apollo management by PERT Systems.

PACC, a system for PERT associated cost reporting, is being developed by S&ID and will be checked out in house during the next quarter. Discussions have been held with NASA on restructuring Apollo general orders to allow better cost alignment. Restructuring of General Orders will not occur until after definitization of the Contract. When such restructuring is accomplished, NASA/NAA procedures for PERT Associated Cost Reporting will be implemented as negotiated.

## ASSOCIATE CONTRACTOR ADMINISTRATION

Considerable progress was made in defining the location of MIT navigation and guidance displays and controls within the command module and in establishing attendant dimensional limitations. NASA, MIT, and S&ID are determining corrective action for physical interference of the sextant and the crew couch.

[redacted]

In a joint review for the selection of a fixed sextant versus an articulating sextant, NASA, MIT, and S&ID agreed upon the fixed sextant installation. While this installation provides a smaller field of view, concurrent simplicity affords higher reliability.

The many recent changes in boilerplate and spacecraft end-article requirements have had a direct affect upon the navigation and guidance-system requirements and schedules. The reduced number of flight articles provides schedule relief, relative to GSE and navigation and guidance systems; however, S&ID is planning to restate the program needs for design-limit integration testing of simulator 2 and for a fully functioning system for spacecraft 001. Consideration is also being given to further discussion of other items.

S&ID has presented a proposed Apollo/Little Joe II interface coordination-and-control procedure to NASA and Convair for review. Based on the results of preliminary coordination, early approval is expected.

## INTERDIVISION PROCUREMENT

An evaluation conducted by Apollo engineering on the development of the command module reaction-control engine resulted in a stop-work order to the Marquardt Corporation and subsequent reassignment of the development effort.

NASA-MSC concurred in the S&ID "make-or-buy" decision and approved the selection of Rocketdyne as a source.

Following receipt of a firm cost proposal from Rocketdyne, a definitive IDWA will be issued and implemented during the next report period.

### Los Angeles Division

The Los Angeles Division is engaged in GSE and test-stand design, testing, and manufacturing programs in support of Apollo.

The testing programs include wind-tunnel testing, antenna radiation-pattern study, compatibility testing, and ablation heat-transfer testing.

### Atomics International

Atomics International is developing and will deliver an IBM 7090 Fortran nuclear-radiation-shielding program, to be used in computing radiation dose levels. Program completion is scheduled for March 1963.

Columbus Division

An analytical study of attenuation system, land and water impact stability study is being conducted. This effort will be completed during the next period.

Autonetics

Autonetics is conducting a study for the design and development of a spacecraft back-up instrument for earth entry. The study will be completed during the next period.

## CONTRACT DEFINITIZATION

To establish a negotiating base for definitization of subcontracts, firm cost proposals received from all subcontractors are now being reviewed. Most negotiations will continue during the next period, but the major part of the change analysis will be performed during the cost reduction exercises now in progress.

Because of the changes in process (a result of the August 1962 phasing schedule) and because of cost-reduction revisions in hardware requirements, study efforts, GSE, and reliability, a delta negotiation platform will be established and included at the time of negotiations, as a change to the approved negotiation target.

| Subcontractor | Limit of S&ID Current Funding 20 September 1962 | Forecast of Contract Definitization |
|---|---|---|
| Aerojet | $ 3,200,000 | November 1962 |
| AiResearch | 4,380,000 | December 1962 |
| Avco | 4,880,000 | December 1962 |
| Collins Radio | 10,500,000 | December 1962 |
| Lockheed | 2,250,000 | November 1962 |
| Marquardt | 4,533,000 | October 1962 |
| Minneapolis-Honeywell | 11,625,000 | December 1962 |
| Northrop-Ventura | 1,900,000 | December 1962 |
| Pratt & Whitney | 8,100,000 | November 1962 |
| Thiokol | 1,030,000 | October 1962 |
| Beech Aircraft | 700,000 | November 1962 |
| Melpar | 64,000 | November 1962 |
| Transco | 123,000 | Fixed Price |
| Alderson Laboratories | 46,000 | Fixed Price |
| Sperry Company | 52,000 | Fixed Price |

Resident Representatives

S&ID subcontractor-management offices, with resident material and engineering representatives, have been established at the following subcontractor facilities:

Aerojet-General Corporation
AiResearch Manufacturing Company
Avco Corporation
Collins Radio Company
Lockheed Propulsion Company
The Marquardt Corporation
Minneapolis-Honeywell Company
Northrop-Ventura Division
Pratt & Whitney Aircraft
Thiokol Chemical Corporation

Beech Aircraft Corporation, Mel-Par, Inc., Transco, and General Electric will be monitored and surveyed on site, on a part-time basis.

Briefing Sessions

The subcontractor second-quarterly briefings were conducted in August by all major subcontractors. The briefings were well prepared.

Scheduled coordination meetings with the subcontractors during the months of July, August and September were completed.

NEW PROCUREMENTS

Antennas

Orders for two of the nine antennas have been placed. Two have been withdrawn as a requirement. Status is as follows:

Recovery Antenna - Bids being evaluated
Beacon Antenna - Specifications being written
Telemetry Radome Antenna - Specifications being written
2KMC HiGain - Specifications being written
Personal Communication - Specifications being written

Cryogenic Tanks

Beech Aircraft was selected as the cryogenic tanks supplier, and an order was released during the report period. Specification control drawings

have been prepared that show the method of sensor mounting and the heater arrangement. Effort is being continued on the test complex amplifier room, instrumentation room, and test cells. Planning for all tooling, testing, and manufacturing is in progress. Facility requirements and justification have been completed and are in the process of being reviewed.

Batteries

The Eagle Picher Company has been approved as the supplier for batteries. Letter-contract and field analysis are planned.

Battery Charger

Proposals have been received, and evaluation is in process.

Propellant Utilization and Gaging System

Proposals have been received, and evaluation of potential subcontractors has been completed.

Oxidizer, Fuel, and Helium Tanks

The approved list of bidders has been revised to reflect more stringent technical requirements. Preliminary drawings and a preliminary schedule have been received.

Positive Expulsion Tanks

The procurement specification and a preliminary schedule have been received. The bidders list has been prepared.

Static Inverter

Proposals have been evaluated and the source-selection presentation has been initiated. A revised procurement specification has been released.

## LETTER CONTRACT AMENDMENTS

Amendment 5 to Letter Contract NAS9-150, increasing funding from 55 million dollars to 60 million dollars, was received and executed by S&ID on 20 July 1962.

Amendment 6 to Letter Contract NAS9-150 was received and executed by S&ID on 11 July 1962. This amendment authorizes PERT system costs for Apollo facilities to be charged to this contract.

Amendment 7 to Letter Contract NAS9-150, increasing funding from 60 million dollars to 85-million dollars, was received and executed by S&ID on 20 July 1962.

Amendment 8 to Letter Contract NAS9-150 was received and reviewed by S&ID. This amendment incorporated a "make-or-buy" procedure for training equipment. Because the basic "make-or-buy" policy has not yet been established, it was felt that acceptance of this amendment would be premature. On 12 September 1962, this amendment was returned unexecuted by S&ID management, with the request that this subject be considered again after the contract is definitized.

Amendment 9 to Letter Contract NAS9-150, increasing funding from 85 million dollars to 115 million dollars, was received and executed by NAA 10 August 1962.

Amendment 10 to Letter Contract NAS9-150, increasing funding from 115 million dollars to 150 million dollars, was received and executed by NAA 10 August 1962.

## CONTRACT CHANGE AUTHORIZATION

Contract change authorization 2 has been received. This contract change defines a complete new technical approach (Part III) of the statement of work that incorporates the lunar excursion module. Copies have been reproduced and distributed for comments.

## FINAL ACCEPTANCE AND INSPECTION OF HARDWARE

Shipping instructions have been prepared for mock-ups 4 and 7, and for boilerplates 1 and 5. These items all have been accepted. Tentative agreement has been reached with NASA on the use of a form for sell-off and for qualifying language that will indicate NASA acceptance (for record only) and S&ID retention and use of the noted boilerplate and mock-ups. GSE will be subject to final inspection and acceptance by NASA.

## DEFINITIVE COST PROPOSAL

Effort is being continued on the definitive cost proposal for presentation to NASA. A delta proposal, itemizing the differences between the original cost proposal and the present statement of work, will be published on 30 October 1962.

This delta proposal will show the deletions and changes in the program that have resulted from the present cost-reduction effort. These deletions and changes are shown in the following list:

| Item No. | |
|---|---|
| | Evaluators |
| 1 | Delete evaluator 4 |
| 2 | Delete evaluator 3 |
| | Note: These evaluators will be deleted as separate items with consideration for learning on evaluator 4 from evaluator 3. |
| | Simulators |
| 3 | Delete simulator 3 |
| 4 | Delete simulator 2 |
| | Note: These simulators will be deleted as separate items with consideration for learning on simulator 3 from simulator 2. |
| | Trainers |
| 5 | Delete environmental-control trainer |
| 6 | Delete service-module propulsion trainer |
| 7 | Delete service-module reaction-control trainer |
| 8 | Delete navigation and guidance trainer |
| 9 | Delete stabilization and control trainer |
| 10 | Delete integrated-systems trainer |
| 11 | Delete communications trainer |
| 12 | Delete instrumentation trainer |
| 13 | Delete command-module reaction-control trainer |
| 14 | Delete egress trainer |
| 15 | Delete electrical-power-supply trainer |

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| Item No. | Mock-ups |
|---|---|
| 16 | Delete mock-up 8 |
| 17 | Delete mock-up 16 |
| 18 | Delete mock-up 17 |
| 19 | Delete mock-up 19 |
| 20 | Delete mock-up 20 |
| | Fixtures |
| 21 | Delete No. F-4 propulsion test stand (Aerojet will double usage of F-1) |
| | Boilerplates |
| 22 | Delete boilerplate 5 |
| 23 | Delete boilerplate 8 |
| 24 | Boilerplate 9 will be a dummy spacecraft. It will be used on SA-7 subsequent to NASA dynamic tests, and will be retrofitted with an inert launch escape system (LES)—jettisonable subsequent to dynamic tests. |
| 25 | Boilerplate 13 will be instrumented to obtain launch-environment data, and will be equipped with an inert LES with provision for proper jettison using live LES jettison motors. Boilerplate 13 will mate with SA-6. |
| 26 | Boilerplate 15 launch-environment instrumentation will be available for installation should a backup launch-environment test be required. Boilerplate 15 will be equipped with an inert LES with provision for proper jettison using live LES jettison motors. Boilerplate 15 will mate with SA-8, and will comprise a dummy spacecraft. |

[redacted]

| Item No. | Boilerplates (Cont'd) |
|---|---|
| 27 | Boilerplate 16 will comprise a dummy spacecraft equipped with an inert LES with provision for proper jettison using live LES jettison motors. It will mate with SA-9. |
| 28 | Boilerplate 18 will be a dummy spacecraft equipped with an inert LES with provision for proper jettison using live LES jettison motors. It will mate with SA-10. Manufacturing will not start until after July 1963. |
| 29 | Delete boilerplate 21 |
| 30 | Boilerplate 22 will be scheduled to fulfill a hi-altitude LES abort mission at WSMR June 1964. Boilerplate 22 will be equipped with a stability and control system (SCS) and a reaction control system (RCS). |
| 31 | Boilerplate 23 will back-up boilerplate 12. |
| | Spacecraft |
| 32 | Spacecraft 002 will be a LES abort in September 1964. |
| 33 | Spacecraft 005 the ablative shave-test process will be modified. |
| 34 | Spacecraft 006 will contain reject or dummy engines. |
| 35 | Spacecraft 009 will be used for the first manned flight. It will mate with SA-111. |
| 36 | Spacecraft 009A service module is deleted. |
| 37 | Spacecraft 010 will consist of a command module only, with appropriate systems for a pad abort test conducted no later than 1 November 1964. |
| 38 | Spacecraft 011 will be programmed for the second manned flight and will mate with SA-112. |
| 39 | Delete spacecraft 012. |



[redacted]

| Item No. | The following changes have also been incorporated: |
|---|---|
| 40 | Delay 78 parachute drop tests subsequent to 30 June 1963. |
| 41 | Reduce 2,000 hours of engineering IBM 7090 computer time. |
| 42 | Reduce the quantity of the breadboard reaction-control system (RCS). Two systems will be used for the planned work of three. |
| 43 | Reduce in-house engineering development testing of vendor components. |
| 44 | Reduce other costs of engineering subcontractor development by 10 percent |
| 45 | Reduce engineering manpower by 7 percent because of the reduction in the depth of development tests and study areas. |
| | The following changes have also been incorporated: |
| 46 | Reorient and redirect development, qualification, and reliability testing from a parallel to a series sequencing program. |
| 47 | Reduce Minneapolis-Honeywell special studies. |
| 48 | Delay Collins special studies. |
| 49 | Review costs of all subcontractor PERT requirements. |
| 50 | Eliminate additional subcontractor reductions that are anticipated as a result of S&ID negotiations. |
| 51 | Delay development of R & D telemeter ground stations, and eliminate one ground station and any partial ground stations to the extent that one R & D telemeter ground station is provided at Downey and one R & D telemeter ground station is provided at WSMR. |

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| Item No. | |
|---|---|
| 52 | Reduce briefing charts by 10 percent |
| 53 | Condense all reports by 10 percent in bulk. |
| 54 | Reduce all preproduction requirements by 10 percent. |

# STABILIZATION AND CONTROL SUBSYSTEMS

## EARTH-ORBITAL MISSION CONTROL SYSTEM STUDY

The initial phase of analog computer simulation was completed. It proved the ability of the stabilization and control system (SCS) to perform satisfactorily in damping out normally expected tumbling rates. The simulation also showed SCS ability to maneuver the vehicle to any desired attitude. This ability is for configurations ranging from the minimum to maximum expected weights and moments of inertia using a single size service module and reaction control jets of either 50 or 100 pounds thrust, provided only one jet is used for minimum impulse limit cycle operation.

The second phase of the analog computer simulation study will be started during the next report period. This will be a 6-degree-of-freedom simulation compared to the two sets of 3-degree-of-freedom equations previously studied. The man-in-the-loop simulation for this phase will have increased display instrumentation and pilot maneuver capabilities.

Electronic circuits will replace some of the control system reaction jet mechanical relays for faster and more accurate response.

There will be a digital computer feasibility study to determine the response to such system nonlinearities as attitude error limiting, dead band, reaction jet switching logic, and response firing characteristics.

Studies of the pseudorate-pulsing technique will continue to determine the effect of changes in system parameters, to optimize these parameters, to determine the response of the optimum system to commands and disturbances, and to determine and study failure modes.

A special report, "Reference Systems for Space Flight," was prepared to provide pertinent data on Apollo operations in such technical areas as nautical astronomy, celestial mechanics, guidance and navigation, and space flight instruments.

## PULSE MODULATION TECHNIQUES STUDY

An analysis of the pseudorate-pulsing technique was completed. An approximate phase plan method of determining switching lines was developed and shows high correlation with preliminary analog computer results.

## THRUST VECTOR CONTROL STUDIES

The first phase of a service module main engine thrust vector control simulation was completed. The results include verification of design approach. The simulation also led to the conclusions that the nozzle servo actuator bandwidth should be no greater than 20 radians per second. Nozzle angular rate may limit at 0.25 radians per second, nozzle acceleration may limit at 3.5 radians per second squared, and nozzle angle may limit at 35 milliradians beyond the maximum deflection toward the center of gravity. Angle feedback around the nozzle produces errors due to inaccuracy in calculating the center-of-gravity location of the vehicle. Disturbances introduced into the roll channel by firing the main engine are negligible.

A study of the service propulsion engine thrust vector control system was started. Initial investigations indicate that redundant actuators can be used by adding a brake to the output shaft of each actuator. Other methods of implementing the use of redundant actuators including failure detection devices are being investigated. The study also revealed that fuel cell dynamics form an important part of the servoactuator response time.

The second phase of the thrust vector control simulation study is scheduled. Studies in anticipation of the third phase, which is to include simulation of the sampled-data quantities from the guidance equipment, have been started and will be continued.

## SERVICE MODULE FUEL CONSUMPTION STUDIES

A report presenting tentative service module RCS propellant requirements in a lunar landing mission was completed. This report included a mission outline defining probable mission requirements.

## ATTITUDE INFORMATION

The interface for attitude information from the navigation and guidance inertial measurement unit and coupling display units (CDU's) to the SCS was defined. The electrical signal implementation is yet to be determined. The navigation and guidance system uses an 800-volt signal at the interface, and the SCS uses a 400-volt signal.

The design and development of a solenoid driving circuit for a single-coil solenoid valve was started. This development is to determine if the added complexity of a dual coil valve is justifiable. The primary problem that exists with the reaction jet system is the minimum impulse capability. A minimum impulse of 0.6 pound-seconds is required to obtain the low vehicle angular velocities necessary for navigational sightings.

BOILERPLATES

Test plans for the boilerplate and prototype SCS simulation effort are approximately 70 percent complete. The SCS functional block diagrams including all modes of operation are 60 percent complete. SCS criteria specifications for all applicable boilerplates and airframe vehicles is approximately 80 percent complete.

EQUIPMENT LOCATION

SCS equipment is being relocated in the lower equipment bay of the command module because of spacecraft structural changes and to obtain the optimum location for the center of gravity.

A preliminary drawing is now being prepared by the structures group to locate the horizon and sun sensor heads in the lower equipment bay of the command module.

These locations will be established when the orientation of the command module is defined for all phases of flight.

EVALUATION AND DEVELOPMENT

SCS evaluation and development tests were started with preliminary evaluation of the fuel valve amplifier demodulator and jet drive circuits. Additional components of this system will be tested, and interface circuitry will be developed during the next report period.

SUBCONTRACTOR ACTIVITY—MINNEAPOLIS-HONEYWELL REGULATOR COMPANY

Management prepared and submitted to S&ID the plans to accomplish specific contract work areas and detailed hardware specifications.

Program master phasing charts have been submitted with the program plan. These charts outline the general activity and their interrelationship.

Program Changes

Honeywell was officially notified that the launch escape SCS was cancelled, and all analytical effort was terminated effective 30 August 1962. Systems and component design effort was cancelled as of 6 August except for follow-up on the acceptance testing of the first functional unit in support of the launch escape stabilization control system (LESCS).

Revised flight concepts for the boilerplate have caused reapportionment of system reliability. The present estimate for boilerplate 16 and 18 configuration is 0.99137.

A reaction jet redundance study was initiated as a result of a change in the propellant supply system configuration.

Milestone and Testing Status

Testing of the DSG31A1 power inverter flightworthy model 1 was 50-percent complete when work on boilerplate LESCS was halted.

Testing of the functional-rate gyro package for shipment to S&ID is complete. Initial vibration testing of a flightworthy rate-gyro package casting with functional gyros in the package has been completed. Acceptance tests have been completed on seven flightworthy gyros. Room temperature tests are in process on the electronic control assembly amplifier circuit. Precision Weston meter movements used in the flight director attitude indicator (FDAI) were subjected to vibration tests. Preliminary testing is complete on the meters for the gimbal-angle, translational-velocity indicator pointers and the FDAI rate pointers and is 75-percent complete on the meters for the FDAI command pointers.

A design and development minor design freeze is scheduled for October 1962. The boilerplate component specification will be completed during the next report period. Prototype final design release is scheduled for 1 July 1963.

# CREW PROVISIONS

## DESIGN ANALYSES

Studies and human engineering design drawings were completed for simulators, mock-ups, and boilerplates. Studies were made and drawings were completed of the individual survival kit and individual radiation shielding.

An analysis was made of the effects of crew motion inside the command module on spacecraft attitude control. Studies were made of the environmental control system (ECS) to determine in-flight maintenance that can be accomplished either in pressure suits or in a shirtsleeve environment.

Location and selection of navigation and guidance panel displays were recommended. Suggested manual overrides were defined for the supercritical gas system in the service module. Studies were made of the interference caused by the location of the center restraint couch with navigation and guidance fixed optics. The initial phase of the controls and displays task was accomplished by the completion of preliminary panel drawings, analytical rationale, and systems data. These were submitted to NASA.

Human engineering concepts of the reaction control system (RCS) and the propulsion system consoles were depicted in full-scale cardboard mock-ups. Design drawings were made of the biomedical monitoring console.

## CREW PERFORMANCE

Simulation test plans were evaluated to determine which plans can be used to provide data on human performance in the Apollo missions. The first revision of the crew performance specification was completed.

Requirements were completed for crew performance test design for Phase II of the 6.1 (6 degrees of freedom) simulator study.

Studies and evaluations were made of the probable frequencies and methods of crew ingress/egress during Apollo missions. The telescoping air lock concept was evaluated.

An analysis of all navigational functions performed at the lower station of the command module was completed, and a series of flow diagrams showing actions to be taken in the event of a subsystem malfunction was completed.

Recommendations were prepared for monitoring requirements of atmospheric constituents in the Apollo spacecraft. An analysis of the metabolic requirements of Glenn and Carpenter during their orbital flights was completed, and a summary has been made of metabolic requirements of the Apollo crew.

Crew performance requirements, particularly navigation sighting, remain a problem area. The ability of operators to perform the optical tasks has not been satisfactorily demonstrated.

Conflicts in simultaneous use requirements and relative accessibility of the two stations during common use by crew members, compounded by the center of gravity problem and system relocation requirements, have not been resolved.

## SIMULATION AND TEST

Criteria and procedures were outlined for the selection of test subjects for crew performance and flight simulation test programs. Air lock mobility tests were made of the 10th and 90th percentile subjects in pressure suits. Display and control requirements were completed for flight simulation studies. Work in the form of time-line data processing and reduction and instrumentation requirements for impact testing was accomplished for boilerplate 1. A lunar and earth orbital dynamics attitude control simulation was completed.

During the next report period, the first 4-day crew performance test run will be started. Data reduction and reporting will be conducted after results of the 4-day run are evaluated.

Flight control simulations for the 6.1 study, Phase II, will be performed to determine man's capability to dampen tumbling, using six degrees of freedom. Performance will be evaluated using various control and display configurations.

Flight control simulations will be performed for the 6.3 study, Phases I and II.

Crew integration simulation will be performed to evaluate man's performance in controlling attitude and to study task sharing by crew members.

Human engineering evaluation tests will be accomplished on mock-ups 2, 4, 7, 8, 10, 12, 16, 17, and 18.

Crew support and restraint systems tests will be started with tower drop tests (boilerplate 1).

Life systems requirements and programming will be completed for the following:

Centrifuge tests
Human engineering and design evaluation testing in the house spacecraft (boilerplate 14)
Environmental testing in the environmental proof spacecraft (airframe 008)
Water egress and survival test (boilerplate 8)

Tests will be performed to evaluate crew member ingress/egress through upper hatch in mock-up 8.

Crew Equipment Design

Following are investigations that will be conducted during the next quarter:

Apollo window configuration
Guidance and navigation, optics
Manual back-up for navigation system
Lighting requirements
Integral lighting
Assist grips and flush latches for spacecraft
Panel color contrast study
Visibility through plumes
Communications
Television coverage
Three- and six-axis controls
Environmental control system controls
Lamp testing
Interior floodlighting location
Vision in space and manual navigation space aids

These investigations relate to simulator, evaluator, mock-up, boilerplate, and spacecraft requirements as defined in life systems definitions and hardware utilization lists.

Crew Support

Freeze-dehydrated foods will be packaged in plastic feeding containers of various sizes and shapes. The foods will be rehydrated; eaten; and judged for taste, reconstitution time, palatability, and digestibility. Results will be used for further study and experimentation.

Several total waste systems will be designed, fabricated, tested, and evaluated for Apollo use.

Drinking devices will be designed, fabricated, and tested for drinking under zero-g conditions.

The spacesuit arm simulator will be completed.

A radiation protection garment mock-up will be initiated, and other methods of shielding will be studied.

The study of the use of the personal parachute as an escape system will be completed.

A study of dimensions for astronaut selection criteria will be completed.

Design Support

The coordination of ECS in-flight task studies will be continued. These studies include the definition of tasks for the normal ECS management identification of ECS failure modes and instruments that must be displayed and for the determination of emergency and routine astronaut activity necessary for successful maintenance, system management, and abort during all mission phases.

Studies will be initiated to eliminate interferences between the navigation and guidance panel and the in-flight test panel.

Justification for increase of human oxygen requirements in the command module will be prepared.

The philosophy and detail design studies of manual controls including size, configuration, and actuation forces will be developed.

The definition of tasks to manage the command module RCS will be initiated. The identification of required flight instrumentation will be accomplished.

Possible extra vehicular tasks that may be required during the lunar orbital rendezvous mission will be defined.

Identification of the electrical power systems EPS display requirements and tasks for normal EPS management will be initiated.

The preparation of a section for the life systems design criteria manual on special considerations characteristic of Apollo will be completed.

Efforts to optimize and to integrate Apollo controls, displays, ancillary devices, crew tasks, and system functions will continue.

Ground Support

System specification, system report procedure for checkout, drawings, and over-all use of GSE will be monitored for human factor requirements within design for mission accomplishment to assure over-all compatibility and safety of the crew. Approximately 1400 GSE drawings are due to be reviewed this coming quarter.

A study of the life systems concept of standarized checkout and monitoring consels panels, reflecting typical gage, and control location will be continued.

Crew Performance and Training

The modification and updating of the human factors analysis procedure will be initiated to improve flexibility and application to changing situations in training and training equipment.

Scoring Method I to record and evaluate qualitative failures and errors in training performances will be refined. The development of the scoring formula for training performances that can be scored will determine composite indexing of diversified subscores in Method I.

The adaptation of Method I for "goodness of fit" to changing specifications of individual part-task trainers, indicating the possibility of separate subsystem evaluation design, will be completed.

Performance validation methodology analysis will be completed on the following:

Environmental control (now in work)
Stabilization and control (including reaction control)
Navigation and guidance
Communications system
Electrical system

Preparation of crew performance and training test design and requirements will be completed for the following studies:

Simulation 6.3, Phase I
Simulation 6.3, Phase II
Life systems 2
Life systems 3, Phase I

An analysis of variance computer program is to be completed.

A development of a computer program for performance validation methodology will be started.

Task Design and Analysis

An analysis of flight crew performance and information flow requirements specific to the telecommunications system has been initiated. This analysis will consider normal and emergency modes including in-flight maintenance considerations.

A comprehensive maintainability checklist for Apollo engineering has been initiated and will be available in the next quarter. This checklist is oriented toward in-flight maintenance requirements relative to the constraints and environments of space.

Detailed studies of operator tasks and workload requirements in the use of the guidance and navigation optics are planned.

The development and implementation of an electronic data processing program for the integrated task index presentation and updating will be accomplished. This system is considered mandatory for maintaining current task information.

A second revision of SID 62-90, Crew Performance Specification, will be started. The date of the next publication will be coordinated with NASA personnel in accordance with their needs and specification of document classification.

In-flight maintenance will involve development of a life systems approach or methodology for conducting maintenance performance analysis and failure effect studies and a continued analysis of individual systems to determine alternate mode and failure effects on crew performance and workload requirements.

Biomedical

During the next period, medical examinations for the simulation and test subjects will be accomplished, and an implementation of the medical briefing and debriefing area will be completed.

Installation and checkout of medical monitoring instrumentation will be studied.

Participation and medical monitoring in the 7-day confinement study is planned.

The readjustment to changes in the work statement involving the ECS will be continued.

Reevaluation of the emergency medical supplies as directed by NASA is planned.

Operations And Safety

Future support of the control-display task group activities will include a more definite review of all systems and the updating of panel drawings and systems analytical data.

Assistance to the task analysis group in determining human sighting error while taking navigation fixes with present MIT optical design instruments will be continued.

The study of window functions related to all phases of the Apollo mission will be continued.

The study of optical viewing aids in conjunction with windows as related to flight instrumentation and rendezvous visual back-up will be continued.

Control-display refinement/advanced concepts study efforts through interpretation of human factors and operational factors requirements will be continued.

The command module control standardization criteria in conjunction with subcontractor and electronics systems development efforts will be continued.

Safe practices for GSE handling and operations of Apollo ground support and operational equipment will be documented.

Maintenance and checkout requirements will be analyzed to determine that adequate safety precautions have been incorporated in design, and an analysis of operations and interface considerations will be completed.

Safety analysis of the earth landing system, complexities involving command module growth, impact attenuation limitations, and problems arising in environmental and equipment developmental areas will be continued.

Hazards analysis will be conducted to determine the adequacy of safety consideration and crew protection for all operations and missions.

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# LAUNCH ESCAPE SUBSYSTEM

## LAUNCH ESCAPE MOTOR

All component parts of the launch escape motor have been designed. Performance changes were incorporated.

At the request of NASA, a design was made of a launch escape system (LES) without active control. The thrust vector control system of the launch escape motor was deleted, and fixed nozzles were designed.

Another redesign of the nozzles and motor aft closure was made necessary by the lower thrust-level requirement for the launch escape motor. This requirement also made necessary a modification of the internal propellant configuration. The nozzle centerlines were moved outboard about 1/2 inch and canted to 35 degrees in relation to the motor centerline to lessen rocket-jet impingement on the launch escape tower structural members. The four nozzle bosses on the aft closure are now symmetrically located in relation to the motor centerline.

A 2-degree, 45-foot resultant thrust offset is being obtained from differentially off-sized nozzle throat diameters in the pitch plane.

The rocket motor aft closure-to-structural skirt joint was redesigned to accommodate the installation of the aerodynamic flow separator.

During the next report period, the development program of the launch escape motor will begin. The initial firing is planned for three motors by the end of 1962. Igniter testing for the developmental verification of ballistics will be completed.

## SUBCONTRACTOR ACTIVITY—LOCKHEED PROPULSION COMPANY (LAUNCH ESCAPE MOTOR)

Lockheed has submitted a revised cost proposal reflecting the effect of program redirection. An analysis of the new proposal has been completed.

Program Changes

Program hardware delivery dates have changed, based upon the August master phasing schedule. These changes are not a constraint upon the overall program in support of the first manned flight.

Milestone and Testing Status

All motor components necessary for delivery of the first inert motor, boilerplate 9, have been received by Thiokol.

All test tooling has been delivered to Thiokol, including the multi-component thrust stand. The thrust stand will require modification, which will be accomplished during the next period.

Four tests in the pyrogen development program have been successfully completed.

The 5-inch batch check test firings were completed, and the data indicated that the ballistic properties meet the required performance specifications.

PITCH CONTROL MOTOR

A third solid-propellant motor was incorporated into the LES. This pitch control motor is fired simultaneously with the launch escape motor and places the LES in the proper abort attitude.

Work on the pitch control motor was added to the existing contract for the launch escape motor. This is proceeding at an accelerated pace to maintain S&ID delivery schedules. All component drawings for the pitch

Program Changes

Major redirection was accomplished, including:

Decision to delete swivel nozzle thrust vector control

Addition of four fixed nozzles, canted 35 degrees from motor center line

Reduction of thrust level of motor

Development of pitch control motor

[redacted]

Milestone and Testing Status

Hardware suppliers, affected by design changes, have been redirected by Lockheed. Revised designs have been released for mandrel, aft closure, and nozzles.

The inert motor has been cast and is being processed on schedule, using mandrel and aft closure from the previous design.

Designs have been completed for the pitch control motor, and tooling design is proceeding on schedule.

Milestones have been revised to reflect the new motor characteristics and scheduled delivery.

The Potrero test bay modification has been completed to accommodate vertical lunar excursion module firing.

Lockheed will deliver the first inert motor on or before 13 October 1962.

The first live motor tests will be conducted at the Potrero Test Site early in November 1962.

TOWER JETTISON MOTOR

Progress has been made on the tower jettison motor program. All motor and igniter component parts were designed, procured, and received by the subcontractor. The first four static igniter tests were conducted. Test results were reviewed and found to be in satisfactory agreement with predicted results. The first inert motor for boilerplate 9 was cast and is being prepared for shipment to S&ID.

The tower jettison motor development program is scheduled to begin with the initial motor firing, which is scheduled for the next period. Most of these development tests will be completed by the end of 1962. During this period, all LES structural-installation drawings will be released.

SUBCONTRACTOR ACTIVITY—THIOKOL CHEMICAL CORPORATION (TOWER JETTISON MOTOR)

Thiokol has been maintaining a schedule position. Based on the August master phasing schedule, the program has been lengthened by 7-1/2 months. S&ID is attempting to obtain General Laboratory firing units through NASA, to reduce costs and guarantee the Thiokol qualification test schedule.



[redacted]

control motor have been released. Essentially the pitch control motor will follow the launch escape motor development program toward the end of the next report period.

MOCK-UPS

Requirements were established and approved for the engineering development test program for the LES. Requirements for fixtures and the test set-up were specified.

Test procedures were defined to establish the ability of the system to separate the escape tower effectively from the command module with and without the application of a simulated rocket motor thrust. The series of tests presently defined will be performed at ambient conditions. Further testing under appropriate environmental conditions will be specified by a revision to the existing requirements.

Drawings were released for mock-ups 9, 11, and 18.

WEIGHT CONTROL

Inertias, weights, and centers-of-gravity were estimated for the passive LES. The current weight of 6600 pounds represents an increase of 700 pounds. This weight includes an air-flow separator, ballast, and pitch motor. Balance and inertial studies for variations in ballast are in progress.

TOWER STRUCTURE

Detail design layouts of the changes to the LES structure associated with the incorporation of the passive control system were completed. All new and changed drawings resulting from this revision have been prepared and released. Major components that were added include an aerodynamic flow separator, a pitch-control motor, and supporting structure. Procurement of material for fabrication of the additional parts has been started.

The LES structure assembly for mock-up 18 will be built using the prototype tooling to provide verification of this tooling and to eliminate the need for tooling with which to build an additional LES structure.

The launch escape motor was changed from a thrust vector control system to a passive control system using a kicker rocket. Because initial passive system loads are slightly less than the thrust vector control loads, changes in tower member size will not be necessary.

Tower geometry and escape rocket nozzle attitude are being studied to eliminate the problem of rocket exhaust impingement upon tower members. The study reveals the new tower geometry to be more flexible than the present tower. A study is in progress to determine the reinforcement required to approximate the present tower stiffness.

FLEXIBILITY

A computer program is being written to calculate the structural influence coefficients and internal loads and stresses of the tower. This analysis will include the effects of the moment fixity at clamped joints.

PRODUCIBILITY OF STRUCTURAL TUBING MATERIAL

Tubing is being procured and tested to determine producibility and design allowables applicable to the Apollo escape tower. Welded and extruded tubing of 6Al-4V titanium alloy is being tested for weldability, response to heat treatment, and mechanical properties. Welded steel alloy PH15-7Mo tubing is being subjected to identical testing.

LES TESTS

The ambient conditions test has been defined.

The escape rocket static test will be conducted during the next period.

Test articles of stainless steel tubing with thermocouples and ablation coating were fabricated for exposure to the exhaust of a Sparrow engine at the McGregor, Texas, test facility. Results of these tests will provide experimental design information and will indicate the direction of additional tower ablation tests.

[redacted]

# ENVIRONMENTAL CONTROL SUBSYSTEM

The installation of components in the forward compartment of mock-up 5 was completed and includes the latest concept of the air lock valve and manual-shutoff valve air-vent covers.

A redirection of various phases of the Apollo program has created new problem areas resulting in a reevaluation and redesign of the system. Numerous studies resulted in corrective action that increased system reliability and in many instances decreased weight.

The net effect of the lunar excursion module mission on the Apollo environmental control system (ECS) will probably be an increase in system weight, particularly if additional plumbing is required to supply cooling to the lunar excursion module.

The cryogenic storage system will probably be changed to accommodate the lunar excursion module concept. System design is flexible, but lead time for forgings for the inner and outer tank shells will dictate system delivery schedules. Changes in fluid requirements resulting from this redirection would require new forgings with resultant slippage of system delivery schedules.

During the next report period the necessary studies will be conducted and design layouts and documentation will be revised to accommodate the lunar orbital rendezvous mission and the change to 100-percent oxygen atmosphere.

The two newly designed configurations of thermal interface material will be fabricated for coldplate conductive cooling evaluation tests to determine the optimum method of conducting heat in a vacuum.

Studies will be continued to determine the possibility of harmful or undesirable results from using combinations of aluminum, stainless steel, and beryllium copper within the water-glycol system.

The left-hand equipment package will be revised to incorporate the redesigned water-glycol reservoir and pump package, as well as the larger regenerative heat exchanger which replaces the counterflow type previously considered.

The interim test facility for the ECS is scheduled for completion during the next quarter. The test chamber to house the ECS will be completed, pressure-tested, and leak-tested. Instrumentation of the chamber, with vacuum feed-throughs for temperature, pressure, flowrate, and power will be started.

Purchase orders for all components of the three-man metabolic simulator will be prepared, and fabrication will be started.

The series of interface conductance tests with the simulated equipment package will be completed.

Tests will be conducted with the hotplates and selected interface materials, and additional plates will be fabricated and tested to investigate such special problems as the effect of clamping arrangements and of normal machine tolerances on interface conductivity.

## SUBCONTRACTOR ACTIVITY—AIRESEARCH MANUFACTURING COMPANY

Apollo engineering manpower for the AiResearch subcontract reached its peak for the entire program in August 1962. The total personnel, as of that date, was 118 (64 engineers and 54 project team engineers).

### Program Changes

AiResearch was directed to delete nitrogen from the oxygen supply subsystem and to use pure oxygen at 5 psia. This will effect a contract cost reduction, but will increase the negative slack in the design layout drawing phase by four weeks because of engineering changes.

In September, at the request of S&ID, AiResearch submitted a revised cost proposal that delineated the amount of effort possible with a revised slipped schedule.

### Milestone and Testing Status

During the latter part of this period, the most critical path on the ECS program shifted from the ECS to subtier contract award for the gas analyzer. This condition is being closely monitored to assure that objectives will not be compromised.

The contract was awarded to Perkin-Elmer, Norwalk, Connecticut, on 29 August 1962.

The development ECS design layout drawings for those components system tests were completed during the report period.

Preparation of development GSE layout drawings is nearing completion. The design layout drawings for the system checkout console are 85-percent complete.

Research and evaluation tests on the glycol pump have been completed, and developmental testing has begun. The research and evaluation tests are considered critical, since the detail design drawing parameters for the first ECS to undergo system test is dependent on completion.

The research and evaluation test phase of the program is on schedule with the evaluation of preliminary testing completed. Integration of research and evaluation tests into detailed drawings was completed during the report period.

[redacted]

# EARTH LANDING SUBSYSTEM

## PARACHUTE

The basic parachute equipment consists of drogue parachutes, main parachutes, and sequencing and actuation devices. The drogue parachutes and their mortars were designed, and fabrication is now under way on test articles. The main parachutes are designed and are currently being tested.

Six drop tests were conducted to evaluate the performance and structural integrity of a single main parachute. Results of those tests showed the areas of local structural strengthening required to withstand deployment at maximum design conditions.

The electrical-initiation system was changed from explosive bridge wire to hot wire. This change decreased weight and complexity. Requirements were established for the sequence controller.

The parachute design philosophy was modified to consider the weight growth in the command module that may result from the addition of instrumentation and equipment. The parachute subsystem for the command module is being designed to successfully recover up to 9500 pounds, rather than the 8150 pounds previoulsy considered.

During the next period, the parachute wind tunnel and drop test programs will be finalized. Tests will be continued to evaluate the operations of the single main chutes, main-chute clusters, and drogue chutes, at both design-deployment conditions and ultimate conditions.

## SUBCONTRACTOR ACTIVITY—NORTHROP-VENTURA DIVISION

The parachute-drop test program comprises the major subcontractor activity. Test 7 of the scheduled ~~135~~ weighted-bomb and parachute-test vehicle drops has been ~~completed at El Centro,~~ California.

Facilities at El Centro have been physically surveyed. Renovation is recommended to accommodate the major phases of the testing program.



[redacted]

Program Changes

The method of firing pyrotechnic devices has been changed from the use of explosive bridge wire to a hot wire system. Because development of both systems was made in parallel, schedule slippage will be minor. Independent deployment for each parachute is incorporated. Single point disconnect of parachute, instead of two point disconnect, has been established.

Milestone and Testing Status

A new drawing list was published incorporating all changes and release dates. The milestone schedule has been developed and tentatively approved by S&ID subject to minor adjustments.

During the next period, GSE sophistication will continue, the environmental profile concept will be studied, and in-flight testing will be increased from 65 to 135 drops.

SEPARATION EQUIPMENT

All engineering information required to install the forward-compartment heat shield system on the early boilerplate vehicles was released.

The development plan for this system calls for a significant amount of testing to be conducted during the next reporting period. A four-phase engineering-development program was established, and the tests associated with the first phase are in progress.

will allow the use of the same antenna for both types spacecraft is being considered. If the modification is unsuccessful, a unique antenna will be required for these three spacecraft. S-band equipment, C-band cabling, and the wobbulator have been deleted from this procurement. These and other less drastic changes are currently being incorporated into a revised procurement specification.

## R & D TELEMETRY ANTENNA EQUIPMENT

The mounting problem that exists with the beacon antennas on Little Joe II airframe spacecraft also exists with the Transco telemetry antennas. A modification of the antenna cannot resolve this problem. Alternate methods are under consideration as a replacement for this antenna on airframe spacecraft.

Known requirement changes are currently being incorporated into a revision to the procurement specification.

## SERVICE MODULE VHF ANTENNA

### Discone Antenna

The procurement of this equipment has been deleted because of revised engineering requirements. This equipment was intended to share RF power with the discone antenna to forestall power breakdown. Recently completed tests of the discone indicate that the discone will sustain the total RF power. In the event there is a future need for a service module VHF antenna, the R & D telemetry antenna equipment will be substituted.

### Recovery Equipment

Recovery antenna equipment supplier bid responses were received and are currently under evaluation.

Effort on the recovery aids during the next period should furnish answers to questions regarding operational implementation and the characteristics of a compatible pulse beacon.

### R & D VHF Omniantenna Equipment

Specifications for the radome, discone antenna, and multiplexers are being reviewed and revised.

Scaled Spacecraft Models

One-third scale models of the service module are being fabricated for antenna pattern testing.

Operational Antenna Equipment

The beacon and high-gain antenna equipment and radome procurement specifications are in preparation. The environmental test vehicle AFRM (002) is the first vehicle requiring this equipment.

Communications-Through-Plasma Study

Effort has begun on the analytical definition of the blackout region during reentry of the Apollo vehicle and on an estimation of the effects of plasma on the telecommunications system.

Preliminary study has begun to determine the problems associated with using a single high-gain antenna.

ANTENNA RADIATION TEST

The design and fabrication of the full-scale spacecraft to investigate antenna patterns and impedance measurements has been terminated as a part of the cost reduction program.

CENTRAL TIMING

The procurement specification for the central timing equipment was released. In coordination with MIT, the reference signal from the MIT master timing source and pertinent data was incorporated in the procurement specification.

TELEVISION

The analog versus digital television studies were completed. S&ID recommends an analog television system. Effort has continued on a study of illumination levels anticipated during lunar missions. The present television equipment consists of one camera and associated electronics.

PCM TELEMETRY EQUIPMENT

PCM Telemetry Studies

Studies to reduce the number of inputs processed by PCM telemetry equipment are under way. The data format assignment computer study has

[redacted]

# COMMUNICATION SUBSYSTEM

## RADIO FREQUENCY

Equipment specifications for procurement of the DSIF transponder and the C-band transponder were released.

An interim report on modulation techniques for cislunar communications was published.

Personal communication parameters are being investigated.

A weight saving of 28 pounds may be achieved by locating the DSIF transponder in the command module.

Various breadboards of the following equipment are in work or undergoing evaluation testing:

1. VHF-AM transceiver
2. VHF-FM transmitter
3. HF transceiver
4. Intercommunication equipment
5. DSIF power amplifier

A complete set of circuit margins for the ground-spacecraft-ground communication links is being completed and will be delivered to NASA during the next period.

## R & D BEACON ANTENNA EQUIPMENT

The location of the four antennas for boilerplate and Little Joe II spacecraft is station 77. The antennas will be circumferentially mounted 90 degrees apart. The exact location in relation to the abort tower legs is being determined.

A problem exists in mounting the proposed antenna design in the structure of the spacecraft. An electrical and mechanical modification that



[redacted]

continued with current emphasis on methods for the reduction of computer time requirements. The synchronization code study has progressed to computer runs. The objective is to select a code that will enable rapid lock with subframe identification.

### Premodulation Processor

The premodulation processor equipment will be used to combine a number of interfaces that existed between the PCM telemetry equipment and the data storage equipment.

### Systems Integration

Test points for the telecommunications equipment were compiled and reviewed to provide adequate coverage of the equipment for GSE, in-flight test and maintenance, and for telemetry purposes.

## WEIGHT AND POWER STUDIES

During the next report period, weight and power reduction studies will be continued. These studies reflect the reduction of redundancy where feasible and the change to a lunar landing mission using the lunar excursion module.

## CREW COMMUNICATION EQUIPMENT

Effort will continue on personal communications. Information is required from NASA concerning personal communications equipment and a definition of the spacecraft lunar excursion module interface.

## SUBCONTRACTOR ACTIVITY—COLLINS RADIO COMPANY

Telecommunications equipment design and development including the construction of advanced breadboards and mechanical layouts was continued. Specifications were approved for the DSIF transponder, the data storage equipment, and the C-band transponder. Collins has received proposals for this equipment plus the PCM telemetry from prospective subcontractors. Hughes Aircraft has been selected to furnish the traveling wave tube for the DSIF power amplifier.

### Program Changes

Reductions in Collins-furnished equipment have been effected through NASA program redirection, cost reduction efforts, and S&ID-Collins contract negotiations. Collins will meet delivery schedules.

Milestone and Testing Status

Breadboard testing is proceeding for the VHF-AM transceiver, VHF-FM transmitter, HF transceiver, and intercommunication equipment. The discone antenna is being development tested.

Planned Activity

Testing of the first engineering models will be completed during the next report period. Second-tier subcontractors will be selected and the first antenna deliveries will be made at this time.

CONFIDENTIAL

# NAVIGATION AND GUIDANCE SUBSYSTEM

## RELIABILITY

The model of the navigation and guidance subsystem equipment operating modes has been reviewed in relation to the preliminary evaluation of inertial reference reliability data received from MIT. The review indicates that the inertial measurement unit (IMU) has a high probability of failure even with anticipated improvements and will require a back-up inertial reference to comply with the required reliability. S&ID and MIT will define reliability figures for navigation and guidance subsystem component equipment that are realistic and mutually agreeable.

## GROUND SUPPORT EQUIPMENT (GSE)

Basic agreement has been established in various levels of navigation and guidance checkout, prelaunch activities, and launch preparations. The aspects of carry-on cables, operational measurements, and in-flight tests are currently being defined. The operating and handling procedure is being revised again to establish the flow of the navigation and guidance system hardware from the time it is delivered to S&ID until it is prepared for shipment to the launch site. The GSE interface between the guidance computer and the PCM telemetry equipment has progressed to the point that S&ID and MIT thoroughly understand each other's problems and are studying the trade-offs and compromises necessary to reach an agreement.

## FIXED-OPTICS INSTALLATION

NASA instructed MIT and S&ID to make feasibility studies of changing from the articulating optical installation to a fixed-optics installation.

An analysis of the IMU errors and their effect upon alignment, testing, and pad operations was completed. This study included all measurable sources of error and considered the IMU to be stationary with respect to the earth. The results of this evaluation indicate that a pad or test azimuth alignment of ±2 minutes of arc is adequate for the system as presently known.

A composite list of all operational measurement requirements was completed. MIT was requested to study these requirements and to provide

the information necessary to assure compatibility with the GSE data channels and the PCM telemetry and to assure uniformity of on-board measurements in the interest of crew facility.

## DISPLAYS AND CONTROLS

S&ID has supplied information to MIT to assist in the sizing, location, orientation, safeguarding, and lighting and color of the various displays and controls in the lower equipment bay. MIT grouped the displays and controls from a functional standpoint and prepared an item-by-item operational flow diagram that reflects the centers of activity. Improvements are expected to result from this study. The panel-mounted equipment, except the coupling display unit, does not require cooling.

## ELECTRICAL LOADS

The electrical load profile was revised. The present profile represents refinement over early estimates in that more is known about each element of the system. The present system minimum-power level is 70 watts during coasting periods when no sightings are being made; maximum power with IMU, optics, and high-level computer operation is 453 watts; the total energy for a model 167-hour mission is 22.79 kilowatt hours, well below the target figure of 50 kilowatt hours for a 14-day mission.

## WEIGHTS

The pieces of the system reported for weight purposes were defined. The entire installation is over the target weight for these items. Since the panels in the lower equipment bay have been located for easy access and viewing, there is an aggregate of unused but unavailable space behind the panels. Some of this volume is waste space because of the form factors of the navigation and guidance items. However, the result is an increased difficulty in locating the command module center of gravity in the most desirable and necessary stations. In keeping with the efforts of the other electronic systems in the lower equipment bay, a higher density installation must be sought for the navigation and guidance equipment while retaining required orientation.

## ASCENT GUIDANCE

A set of guidance equations was written utilizing an explicit solution of Kepler's laws and constant attitude steering that will guide the launch vehicle to a specified coast ellipse with the desired orbital inclination. These equations have been coded and will be used after final checkout of the vehicle dynamics package.

A simple three dimensional trajectory computation program in which all input data is read in and computations made in a single inertial frame was written for initial evaluation of adaptive guidance. This technique, under development by NASA, is planned for use in guiding Saturn vehicles during the ascent phase of Apollo missions.

Simulated guided flights employing pitch-plane steering functions consisting of multivariate polynomials of 8, 36, 47, and 57 terms designed for 100-, 200-, and 300-nautical mile orbital injections were run. The results obtained by NASA in initial studies of injection errors due to adaptive guidance was partially verified. Errors ranging from 0.33 to 0.05 degrees in flight path angle and from approximately 1100 meters to 56 meters in altitudes were obtained for 100-nautical-mile orbits based on cutoff at circular velocity. Yaw and roll steering functions as well as cutoff functions for meeting specific parking orbit requirements are under development by NASA and have not yet been obtained by S&ID.

## GUIDANCE COMPUTER SYSTEM ANALYSIS

The navigation and guidance computer system and the relationship to other Apollo subsystems is being evaluated.

Navigation and guidance to Stabilization and Control System interface problem areas were defined. Solutions for switching of controls and driving of associated displays have been completed for switching of the steering functions, the attitude ball indicator, the error indicators, and the MIT attitude error signals. The 400-cps and 800-cps inconsistency between the two subsystems and the problems in optical hand rate controller are under study.

Equipment required and accuracies involved for navigation fixes with the sextant are under study. Life systems support to delineate crew response and reading accuracy studies has begun.

Vehicle orientation for acquisition and general analysis of vehicle motion is being studies.

The navigation and guidance PCM telemetry requirements are being established. Redesign of the Apollo guidance computer (AGC) to reduce hardware has begun. Combined system integrated tests involving the AGC and associated GSE equipment were initiated.

## APOLLO GUIDANCE COMPUTER EVALUATION

Requirements for the AGC to solve the guidance and control problems are being evaluated and established.

Several reports describing AGC logic, telemetry, and mechanizations were published.

Double precision subroutines for division, addition, "dot" product, matrix multiplication, determination of square root, and multiplication have been written and are being checked out.

Ascent, abort, and reentry guidance mechanizations are being studied.

Phase I digital simulation will involve a nonreal-time closed-loop vehicle simulation within an IBM 7090 for all mission phases. The AGC simulation is complete and available for program checkout.

Phase II analog digital simulation will form the basis for all latter real-time simulations since it will be designed to allow the replacement of simulated hardware by actual system hardware. A flight table requirements report has been published, and work continues on the evaluation of computer equipment for simulation. A breadboard AGC was found to be essential to the simulation.

Phase III hybrid simulation will involve the updating of Phase II simulation by actual hardware as it becomes available. Documents have been published describing the general equipment, schedules, and signal flows.

SCIENTIFIC PROGRAMMING

Problems in the three-dimensional ascent trajectory simulation program is being eliminated. One test case has been run satisfactorily, and improvements are being programmed. A new iterative process for the three-dimensional rendezvous program is being written, and the lunar rendezvous sensitivities program is in production.

The explicit guidance technique simulation program is in production.

The one-impulse deorbit program and the back-up transearth injection guidance program are being revised and are in checkout.

The rendezvous homing initiation program has been completed. The generalized IMU error equation program is 80-percent complete. The on-board computer sampling rate program has been run successfully for one test case.

SEXTANT

Analysis of the motion control capability of sextant images in terms of the proposed MIT configuration will continue. The objectives of this analysis are to determine the nature of the controlling signals to the vehicle, to assess the extent to which such controlling signals are realistic, and to determine the sextant required to make a successful observation. Subsequent to this work, study of all questions relating to the nature and success of navigation techniques traveling to and in the vicinity of the moon will continue.

SATURN INTERFACE PROBLEMS

Technical and hardware interface problems will be delineated. Ascent guidance and translunar injection guidance computations are to be performed within the command module under back-up conditions. One of the problems concerns the functions of the analog guidance signal processor in the Saturn guidance system.

GUIDANCE PHASES

Studies in ascent guidance covering the flight phases through translunar injection were initiated.

The three-dimensional ascent trajectory program will be expanded in successive steps to handle all guidance phases through translunar injection including the simulation of three-dimensional orbital transfer guidance.

Characteristics and adequacy of path-adaptive guidance for satisfying specified earth orbital requirements will be investigated.

The studies will compare explicit guidance with adaptive guidance in respect to mechanization complexity, steering-loop dynamics, required computation rate, propellant consumption, extent of precomputation of constants, accuracy, and other problems arising during development and actual flights.

An ascent phase back-up navigation and guidance configuration will be determined as part of a total primary back-up system. Associated interface problems in transmitting externally generated guidance commands and discrete signals to the Saturn control system will be resolved.

The three-dimensional ascent guidance program will facilitate specification of the final guidance equations and logic decisions to be programmed on the computers that will be used during a space mission.

A modified MIT guidance scheme that is under study will simplify the computer requirements and reduce heat-loads.

The established flight plans for earth orbit mission entry guidance analysis are as follows:

| Entry Plan | Thrust Angle (Deg) | V (Ft/Sec) | Burn Time (Sec) | Free Flight (Sec) | Entry Angle (Deg) | Max g | Total Entry Range (N Mi) |
|---|---|---|---|---|---|---|---|
| Rolling | 90 | 1034 | 30 | 190 | 2.25 | 10 | 1762 |
| Lifting | 90 | 1786 | 50 | 90 | 4.0 | 3.9 | 2038 |

A set of adaptive guidance equations for three-dimensional flight will be formulated, programmed, and tied to a detailed three-dimensional ascent trajectory program.

During the next period, studies will be conducted on problems in meeting various guidance objectives, and an analysis will be made of parking orbit and translunar injection errors due to the Saturn IMU, accelerometer errors, and guidance mechanization.

The three-dimensional ascent trajectory program will also be employed in studying explicit guidance with necessary detail for development of an integrated set of guidance equations.

Primary study effort will be to determine the required initial conditions of the adjoined set of differential equations associated with the Pontryagin maximum principle method. These initial conditions should be determined as functions of the initial conditions of the actual physical system. The alternate numerical analysis problem would basically be concerned with establishment of an appropriate convergent iteration procedure to determine control variables in numerical form.

Study will be directed to the use of transition matrices rather than finite differences in Kalman's optimum control for the two rendezvous problems.

# COMMAND MODULE STRUCTURE AND SUBSYSTEM INSTALLATION

## FABRICATION

The first boilerplate milestone attained during the report period was the manufacturing completion, in July, and acceptance by NASA, in August, of boilerplate 25. This article was prepared for delivery to the Manned Spacecraft Center, Houston, in August, becoming the first manufactured item to be delivered to NASA on the Apollo spacecraft program. The second milestone was the officical acceptance by NASA of boilerplate 1 in September. This boilerplate was delivered on schedule to the laboratory in September for instrumentation prior to land and water drop tests.

The first fiberglass aft heat shield was completed in August, five days ahead of schedule.

A highlight of the command module mock-up activities during this period was the design engineering inspection (DEI) conducted in July by NASA representatives and S&ID engineering personnel. A simulated flight (earth and lunar orbit) was made by R. R. Gilruth, Director of the Manned Spacecraft Center in Houston, C. W. Frick, Manager of the Apollo Spacecraft Office in Houston, and Astronaut Virgil Grissom.

## MOCK-UPS

Mock-up 3 (cabin interior arrangement) and mock-up 5 (cabin exterior equipment) were also included in the engineering inspection, which represented the design and configuration of Apollo and the modifications resulting from the June informal review.

Mock-up 3 was displayed 12 September at the Manned Spacecraft Center during President Kennedy's tour of the United States space facilities. This mock-up was completed in June and maintained to the latest configuration until official acceptance by NASA in September, before being shipped to Houston.

Scheduled for completion during the coming period are boilerplates 3, 2, and 19 on 30 November, 21 December, and 28 December, respectively.

In the November mock-up inspection conducted by NASA, the focus will be on 18 complete mock-ups (launch escape tower, command module,

service module, and adapter). This mock-up is scheduled for completion on 9 November. Also scheduled during the next quarter are mock-ups 12 (crew support system, 28 September), the command module portion of mock-ups 9 and 11 (handling and transportation, 5 October and 12 October), and mock-up 2 (cabin interior, 19 October).

During the next period, engineering information will be released to update mock-up 2 (cabin interior arrangement) to the latest design configurations.

## BOILERPLATES

The basic structural-design effort for boilerplates 1, 2, 3, and 19 of the command module were completed and a complete set of drawings were released.

During the next period, the systems-support structure will be designed to accommodate individual boilerplate articles and redesigns necessitated by program redirection.

## BOILERPLATE CREW COUCHES

Crew-couch drawings for boilerplates 20 and 21 were released during this period.

## CREW ACCESS HATCH

Studies of the crew access hatch were continued during the report period. The linear-shaped-charge test program was continued through shearing a series of panels of various gauges with a variety of explosive grains.

During the next period, the hatch-port-cover mechanism will be designed for compatibility with an inward-opening door.

The outward-opening mechanical hatch design will be held as a backup, and further work will be done on a matching port-cover configuration.

## HEAT SHIELD

Basic design layouts of the command module outer structure (heat shield substructure) are 95-percent complete.

Definitions of cutouts, maintenance panels, window covers, and umbilicals in the heat shield were established and configuration-control drawings were prepared.

All heat-shield structural drawings will be released during the next period.

Attachment and fabrication techniques will be defined. Mechanical and physical property tests, thermal property tests, structural integrity tests, vibrational tests, acoustical tests, and thermodynamic tests are shceduled for the next period.

## SUBCONTRACTOR ACTIVITY—AVCO CORPORATION (HEAT SHIELD)

Progress has been made in the areas of aerodynamic design and test, heat shield design, thermodynamic and structural analysis, and materials development. Comparisons show that Avco's 5026 formulation is superior.

Investigation of adhesives for the flexible bond between the heat shield and substructure continues for a suitable adhesive to withstand environmental temperature extremes. Mechanical fasteners will be required. Suitable fasteners and the method of attachment are being evaluated.

### Milestone and Testing Status

Major milestone accomplishments include definition of abort, ascent and reentry trajectories, completion of master facilities tools, and completion of materials screening tests.

Ablative materials have been explored in areas of thermal diffusivities, surface oxidation, thermal conductivity, optical properties, impact studies, and turbulent pipe tests. Refined variations of Formula 5026 seem satisfactory.

During the next report period, the pilot plant is to be in operation, the attachment interface in substructure will be defined, heating and pressure distributions for all trajectories will be determined, complete composite panel will be tested, ablative material will be selected, and all layouts will be released.

## AIRLOCK AND DOCKING

The single-hatch concept will be developed during the next period. It will have a remotely controlled shroud over the radome and a hatch from the command module to the lunar excursion module that can be opened after docking. There will be no immediate need for docking and latching devices until orbiting spacecraft are ready for rendezvous exercises.

A command-to-service module, lunar excursion module docking procedure and lunar excursion mission will be engineered.

Simulator and mock-up exercises will be continued to develop hardware.

## INNER STRUCTURE

Production drawing release will be completed during the next period.

Computer programs are being written to optimize structural-load paths. Programs yielding influence coefficients and internal force distributions are planned for the spherical heat shield, the conical panels (egress hatch), and the conical shells.

## WEIGHT CONTROL

An extensive weight trade-off study was made to minimize weight. As a result, a weight saving of almost 500 pounds was accomplished.

A comprehensive center of gravity study is under way to obtain a more desirable position at entry.

The relocation of major items of equipment and increase of the package density of equipment in various bays will be investigated during the next period.

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# SERVICE PROPULSION SUBSYSTEM

## PRESSURIZATION

Design layouts and detailed analysis of the system are continuing. Studies to define the system requirements necessary to meet final engine requirements are in progress. Preparation and release of pressurization-subsystem detail drawings have begun and will continue through the next period.

## TANK CONFIGURATION AND DISTRIBUTION

The preparation and release of detail drawings have begun and will continue through the next period.

## PRELIMINARY FLIGHT-RATING TEST-ENGINE TEST STAND

The engineering drawing release has been completed, except for those details affected by the engine installation.

Manufacturing effort is ahead of schedule at this time. Detail fabrication and assembly will continue through the next period.

## MATERIALS AND PROCESSES

### Seal Evaluation

Plastic O-rings and metal seals are being evaluated under maximum and minimum compression to determine the feasibility grooves being recommended by the manufacturers. A sealing boss design incorporating a dual seal has been developed. Two different V-shaped metallic seals are currently being evaluated for use with the sealing boss.

Initial seal evaluation with test hardware will be continued during the next period, including proof-pressure testing, leakage determination, temperature soaks, pressure cycling, and reuse.

### Tube Brazing

Compatibility tests were completed with brazing alloys in nitrogen tetroxide. Gold-base alloys exhibited the best properties. Also, the joining of dissimilar metals was investigated.

The development of basic welding and brazing processes, as well as methods of joining dissimilar metals, will be continued.

Titanium Compatibility

Immersion and impact testing will be started during the next period.

## SERVICE-PROPULSION ENGINE

During the next report period, layouts and analytical studies will be made to establish design of the propellant feed lines, insulation, and closeout of the aft end of the engine compartment. A definition of the required engine installation, removal, and ground handling attachment provisions will be established. Extensive injector testing will be initiated. Injector chamber compatibility tests will also be initiated. The subscale engine program at AEDC will be completed.

## SUBCONTRACTOR ACTIVITY—AEROJET-GENERAL CORPORATION (SERVICE MODULE PROPULSION ENGINE)

Accural costs are in excess of budget curves, and corrective measures are being taken to reflect the current cost reduction exercise. Contract requirements are to be defined.

Program Changes

Aerojet has reoriented their program to conform with availability of the test chambers at AEDC.

Milestone Scheduling

The revised milestone schedule is compatible with the indicated availability of the AEDC test facility plan.

The schedule slippage is the result of the design change to a nozzle ratio of 60 to 1 and additional required nozzle fabrication time.

# SERVICE MODULE STRUCTURE AND SUBSYSTEM INSTALLATION

## FABRICATION

Included in the 10 and 11 July mock-up engineering inspection were mock-up 4 (service module and adapter interface) and mock-up 7 (complete service module).

On 2 August, apollo engineering received instruction from NASA to reduce the weight of boilerplate service modules 9, 13, 15, 16, and 18. This change, resulting from a weight increase of the Saturn S-IV, required a configuration change from steel to aluminum. Initial detail fabrication of the first aluminum module began on schedule, 14 September. This module is 6 weeks behing schedule.

Final assembly of the first steel service module was completed in August, 18 weeks ahead of schedule. This ahead-of-schedule condition was the result of the 7 August schedule slip and the use of this module being reassigned to boilerplate 12. A structural assembly "A" change drawing is currently in process. No problems in meeting schedule are foreseen.

Service module accomplishments scheduled for the fourth quarter include completion of the first aluminum module, initial assembly effort of the second and third, and detail fabrication of the second steel module. Service module mock-up activities will include the scheduled completions of the service module portions of mock-ups 9 and 11 (handling and transportation), and 9 November for the service module portion of mock-up 18 (complete mock-up).

## DESIGN

During this period, engineering information has been released for the manufacture of mock-ups 7, 9, 11, and 18.

The service module structure was modified to incorporate the new command module separation system caused by changes in spacecraft design.

The stress analyses of boilerplates 9, 13, and 15 were completed, and the drawings were released. The separation system was completely redesigned, and all effort on the service module Stage I stopped on 12 July 1962.

The structures and thermal protection system section of the Apollo General Test Plan were reviewed, and necessary corrections and additions were made.

All structural tests will be delayed unless test-equipment acquisitions are made. All critical equipment requirements have been submitted to NASA for approval.

Effort during the next period will be directed toward the maintenance of released drawings, the addition of ballast as weight, and the incorporation of systems into the support structure. The space-vehicle booster-separation system will be selected and analyzed. Weight trade-off studies will be conducted on structural components, and other weight trade-off studies will be continued. A stress analysis will be performed on boilerplate and spacecraft drawings.

The primary activities of the next period will be the completion of detail design and the preparation of drawings. The final release of drawings for systems to be used on early boilerplate vehicles is scheduled for the next quarter. A drawing of the major service module items will be released at this time.

Space and mounting provisions for the RCS engine and related equipment will be established and made final. Thermal-conductivity studies of the service module shell will be conducted. Methods of attaching thermal materials will be investigated. The service module fairing and adapter access will be delineated for manufacturing, assembly, installation, checkout, and launch pad operations. These data will apply to launch complexes 34, 37, and 39. The equipment arrangement will be defined for the scale models of mock-up 18. A design study will be conducted to define the most desirable system configuration for the reaction control motor.

Program Changes

The supplier has been directed to reorient the qualification and reliability program to a series-sequencing rather than a parallel-sequencing effort. Detailed test requirements have been outlined.

Milestone and Testing Status

Significant milestones accomplished during this reporting period are as follows:

One hundred-percent occupancy of Apollo facility
One hundred-percent design release of first breadboard module
Start of accelerated life tests on components
Start of initial environmental testing
Complete first experimental module assembly
Complete procurement of test stands
Submittal and approval of GSE specification

SUBCONTRACTOR ACTIVITY— PRATT & WHITNEY AIRCRAFT (Fuel Cells)

The fuel cell design, development, and test program follow planning as defined within PERT and milestone constraints. Engineering drawings have been released on the initial breadboard module. Component redesign and component and single cell testing are under way. Major technical problems have been mutually resolved so that the program as currently paced meets Apollo requirements.

# ELECTRICAL SUBSYSTEMS

## SYSTEMS ANALYSIS AND EVALUATION

The use of incandescent rather than fluorescent lamps for floodlighting has progressed from the study phase to laboratory tests to determine further advantages to the incandescent system. Laboratory tests on the use of fluorescent lamps were completed.

Design drawings and procurement specifications of the command module-to-service module electrical umbilical connector were begun.

Laboratory tests of thermal and magnetic circuit breakers were completed during this period in addition to tests on two 400-cycle 3-phase static inverters. Both inverters failed requiring rework and new tests. These evaluation tests are to be completed during the next period.

Redesign of the launch escape system (LES) sequencer incorporating pitch control to replace thrust vector control was completed. Breadboard fabrication and test of the abort sequencer is in progress.

Procurement specifications for general purpose electrical connectors were begun.

Facility and equipment requirements remain critical support items that can seriously affect development schedules.

An analysis of the three potential sequencer subsystem circuit philosophies was performed.

A list was made of the possible mathematical, statistical, and engineering problems that may have to be analyzed by computers.

Three proposed primary-power distribution circuits were studied and analyzed from a system success standpoint to determine the most functional system.

The electromagnetic interference control specification was revised.

A specification for the application and testing of electrical bonding on Apollo spacecraft was begun.

An investigation was made on grounding and shielding techniques for circuits associated with hazardous devices.

The historical background of the transition from the initial concept to the present Apollo electrical power system (EPS) is being established and will be continued on a current basis. The purpose of this project is to maintain a complete history of the Apollo EPS engineering problems that have been encountered and a detailed description of their solution.

Test plans and schedules were detailed for breadboard, development, and qualification testing of sequencer configurations.

The electromagnetic interference specification for the Apollo space system is being revised.

During the next period, the abort sequencer design using relays will be modified to show the change to hot-wire pyrotechnic initiators.

Floodlighting system design and test specifications will be prepared.

Effects upon sequencer design of triggering methods of the General Laboratory Associates and Aerojet-General types of firing units will be determined and evaluation tests will be conducted.

Procurement of explosive bridge wire systems to the specification for flight vehicles will be started.

The relay sequencers for boilerplates 6, 12, 22, and 23 will be fabricated and tested for flight worthiness. The solid-state sequencers for boilerplates 13, 15, 16, and 18 will be fabricated and tested for flight worthiness. Test procedures will be detailed for flight worthiness, development, and qualification testing of the sequencer.

Mission simulation analyses of revisions to the Apollo LES, earth landing system (ELS), and other system schematics will be continued as design changes are integrated. All future electrical component subsystem and system schematics initiated by S&ID will be reviewed to avoid the creation of, and susceptibility to, transients and electromagnetic interference.

POWER DISTRIBUTION

Suppliers were selected for the battery, inverter, and battery charger.

A revised load analysis was completed based on the present mission operational requirements and system energy usage.

Design requirements were established for power and control relays and system components.

Analysis of battery system requirements resulted in the deletion of one battery charger and a reduction is battery capacity.

Test plans and schedules were detailed for evaluation, system breadboard, and house spacecraft testing of the power distribution system.

Power distribution system instrumentation requirements were established for telemetering, in-flight test system, GSE, and display panels.

Revisions to the battery, battery charger, and inverter specifications will be completed to conform to changed requirements.

Test procedures will be detailed for system breadboard and house spacecraft electrical power distribution tests.

Spacecraft schematic diagrams and system performance specifications will be completed.

## PYROTECHNICS

The General Laboratories Associates firing units and the Aerojet-General EBW initiators will be used for the ignition of the three solid-fuel rocket motors. All other pyrotechnic functions will utilize 1-amp, 1-watt, no-fire, hot-wire initiators. An EBW system procurement specification was prepared.

A reliability growth study program during development firing of initiators and rocket motors was established.

## SEQUENCER

Functional diagrams and schematics were prepared for boilerplates 6, 12, 13, 15, 16, 18, 22, and 23. A breadboard sequencer was fabricated and was operationally tested for boilerplate 16. A prototype solid-state sequencer for boilerplates 13 and 15 was designed, and fabrication was begun.

## FUEL CELL

The fuel cell instrumentation list was revised, and the revisions were coordinated with the supplier and NASA. The revisions involve the removal of the sensors specifically planned for ground diagnostic tests. The in-flight instrumentation sensors were not affected.

Plans for White Sands fuel cell system testing were completed, and plans for house spacecraft fuel cell system tests are near completion.

The squib valves and reactant flow sensors were removed from the fuel cell module design and placed nearer the reactant tank in the fuel cell system. The fuel cell procurement specification is being revised to show this and the other changes made during the past quarter.

It was determined that the most advantageous method of mounting the fuel cells was to use the shock mounts with a conical section between the mounts and the service module floor to provide additional support. These decisions result in a small, light package that can be easily tested in vibration to ensure proper design.

The initial fuel cell system radiator design and formulation of the radiator test plans will be completed in the next period. The fuel cell procurement specification will be revised.

The entire system design for the single module tests of boilerplates 16 and 18 will be completed, and test plans will be formulated.

The initial build-and-test running of the fuel cell module will be accomplished.

## FUEL CELL MODULES AND CRYOGENIC TANKS

A study was made to determine the best location in the service module for the fuel cell modules and cryogenic tank. This location was determined to be sextant four for all three of the fuel cell modules, and sextant one for all the cryogenic tanks. The result is a reduction in tubing requirements between sextants increasing system reliability without affecting spacecraft center of gravity. The total tubing lengths were determined to ascertain secondary collant loop pressure drops.

A study was initiated to analyze the Apollo LES and ELS through IBM-7090 mission simulation techniques.

The service module-to-command module umbilical disconnect procurement specification was reviewed to comply with radio-frequency interference specifications.

A study was performed to determine several possible methods for suppressing transients across the relay coils of the ELS and LES sequencers for boilerplate 6.

A study was conducted to perform system circuit analyses by binomial rather than manual methods.

A study was completed to determine the best method of wiring hot-wire initiators from the earth landing sequencer.

[redacted]

A study was initiated to determine the mathematical relationship between conductive wiring and power loss, voltage drop, time resistivity, wire length, weight per unit of length, and current. This study was conducted to determine the minimum wire weight for each intended function.

During the next period, studies of the arrangement of electrical power system components in the command module lower equipment bay will be continued. Power distribution system trade-off studies will be continued to optimize system configuration, reliability capacity, weight, and performance.

## SUBCONTRACTOR RELATIONS

Process specifications and evaluation test procedures for the firing units were prepared.

During the next period, procurement specifications for power and control relays and miscellaneous components will be completed and will be released to suppliers.

Procurement specifications for the general purpose wire, general purpose circuit protectors, and command module-to-service module electrical umbilical connector will be completed.

# REACTION CONTROL SUBSYSTEM

## PROPELLANT SYSTEM

Design layouts of the command module reaction control system (RCS) are proceeding on the basic configuration presented during the preceding period. Design layouts of the service module RCS are proceeding on the quadruple modular system. Refinement and optimization studies, directed to an increase in reliability and a reduction of weight, are continuing on both systems. The preparation and release of detail drawings will continue through the next report period.

## BREADBOARD DEVELOPMENT TESTING

Design of the breadboard oxidizer and fuel tanks has been completed. The service module RCS test stand is being redesigned. Fabrication of the command module RCS breadboard test stand is nearing completion.

During the next quarter, Phase I components will be received and subjected to individual functional tests. They will then be assembled on the test stands and the complete system will be extensively tested to obtain developmental data.

## MATERIALS AND PROCESSES

Over 50 compounded materials have been immersion tested in both nitrogen tetroxide and 50-50 unsymmetrical dimethylhydrazine/hydrazine. No rubber compound has exhibited a completely satisfactory compatibility with nitrogen tetroxide. Halogenated plastic materials such as Teflon, Aclar, and Tedlar have exhibited excellent compatibility with nitrogen tetroxide, but have very poor sealing properties and flexibility. Most of the selected materials when exposed to 50-50 unsymmetrical dimethylhydrazine/hydrazine mixture have shown excellent compatibility and a very low permeability.

## MOCK-UPS

Mock-up information drawings have been completed which reflect the current RCS configurations for both the command and service modules. These will be used to install the systems on mock-up 18. Mock-ups 5 and 7 are now being updated to latest design.

COMMAND MODULE ENGINE

The Rocketdyne authorization for the design, development, and testing of the command module reaction control engines will be negotiated and released during the next report period.

The potential saving associated with reorientation of the thrust vectors will be resolved and, if practical, design changes will be initiated.

The command module rocket engine installation drawing will be released.

The command module reaction control engine duty cycle will be defined.

SERVICE MODULE ENGINE

Phase I of this test program which will determine the capabilities of the J2A test cell at AEDC with an operating Apollo RCS engine will be completed during the next period.

The procurement specification and specification control drawing will be modified to reflect the latest changes in minimum impulse, duty cycle, and engine configuration.

The duty cycle for the service module reaction control engines will be completed.

The procurement of 32 additional engines for use on boilerplates 16 and 18 will be started.

RCS checkout procedures will be established.

SUBCONTRACTOR ACTIVITY— THE MARQUARDT CORPORATION (Service Module Reaction Control Engine)

The letter contract has been amended to delete the command module reaction control engine.

Program Changes

All documents and reports have been revised to report on the service module reaction control engine only.

Marquardt has withdrawn their requests for special test equipment for Ogden, Utah, and off-site propellent storage facilities.

[redacted]

Milestone and Testing Status

Design criteria for prototype engine hardware has been released. The following components are affected:

Engine thrust chamber

Invector head assembly

Solenoid valves

During the next period, Marquardt will define purchase order, complete prototype development testing, conduct experimental flight rating test on the engine, continue qualification and reliability tests on components and engine, and conduct formal reliability demonstration tests.

[redacted]

[redacted]

# SPACECRAFT ADAPTER

## DESIGN AND FABRICATION

Design changes and information on all mockup adapters were released during this period.

The basic structure of the pad-abort adapter for boilerplate 6 was fabricated. Redesign is in progress to accommodate the addition of the redesigned command-to-service-module separation system.

The steel adapter for boilerplate 12 was fabricated. Adapters for boilerplates 9, 13, 15, and 18 were changed from steel to aluminum to lessen weight.

An air-conditioning heat barrier will be added to the adapter during the next period.

## STRUCTURAL SHELL CONFIGURATION

The structural shell configuration for the adapter module was changed to utilize honeycomb shell to transmit axial and bending loads. A redesign of the joint between the service module and the adapter permits it to act as a continuous connection. The outer shell can then carry body-bending and axial loads, eliminating the necessity for heavy longerons.

A design study will be conducted to define the most desirable method of transferring loads and accomplishing the module separation without introducing concentrated loads into the structure.

The outer shell was resized. The adapter is 154 inches in diameter and 116 inches long, and is constructed of four aluminum honeycomb panels. A manhole door will be provided for access, and two 12-inch-diameter hand holes will be provided for filling the fuel and oxidizer tanks.

The new structural configuration, while providing a significant weight saving, does not include any major structural members in the axial direction.

## SEPARATION SYSTEM

The spacecraft and adapter will be separated from the booster by posigrade rocket motors mounted on the exterior of the adapter.



[redacted]

During the next period, the spacecraft/booster separation system will be selected and analyzed. The study of structural requirements for the lunar-excursion-module adapter transition section will be continued. The location of brackets for mounting of posigrade rockets will be determined. Similar action will be taken to provide reaction-control-system provisions if required.

[redacted]

# SPACECRAFT GROUND SUPPORT EQUIPMENT

## GROUND SUPPORT EQUIPMENT REQUIREMENTS

A preliminary report, "Apollo Checkout Concept," was prepared describing an evolving checkout system for special test areas for AMR pads 34 and 37. The report includes information on integration, acceptance, and maintenance of the GSE and Apollo spacecraft systems.

A GSE system concept report on boilerplates 3 and 19 was prepared. An outline was prepared for the GSE concept for boilerplates 13 and 15 and is being written.

A GSE concept concerning the propulsion-development test stands (1 and 2) is being developed. The document will be developed in three parts as follows:

| | |
|---|---|
| Part I | Stand 1, test fixture 2 |
| Part II | Stand 2, AFRM 001 (local checkout) |
| Part III | Stand 2, AFRM 001 (remote checkout) |

Part I of this document is 80 percent complete.

The GSE requirements for the supercritical gas storage system were 30 percent completed. Requirements for the command module and service module reaction control system (RCS) checkout unit, the service propulsion system (SPS) checkout unit, and launch escape system (LES) pneumatic-hydraulic checkout-and-servicing unit were established. Preliminary design and procurement specifications for R&D instrumentation, GSE checkout, and maintenance equipment were completed.

A procurement specification was prepared for the earth landing system (ELS) bench maintenance equipment and the barometric checkout unit. A preliminary design requirement specification for the pyrotechnics and sequencer checkout unit for boilerplate 6 was completed. The recent redirection pertaining to pyrotechnic devices resulted in extensive changes to the sequencer circuits and the checkout equipment.



[redacted]

Requirements for the electrical power checkout group for boilerplate 6 were determined.

During the next period, studies will be made to determine the GSE requirements and placement for support of the house spacecraft.

The requirements for the integrate/transport/launch technique to be used at pad 39, AMR, are being examined and will be included in a future concept report.

The GSE system concept for boilerplates 13 and 15 will be completed.

The GSE system concept for the propulsion-development test stands will be completed.

The specification for the fuel-cell service dolly will be completed.

The specification and schematic diagram for a fluid trim control set will be completed.

The determination of GSE requirements for the supercritical gas storage system will be completed.

The preliminary drafts of specifications for the command-module GSE verification simulator and the launch escape tower intermodule simulator, complete with block diagrams, logic diagrams, and definitions of all interfaces will be completed.

## GSE MECHANICAL DESIGN

Design of 25 items of auxiliary and handling GSE was completed in support of boilerplates 1, 2, 3, 6, 9, and 19.

## GSE CHECKOUT SYSTEMS

A report was submitted to NASA which shows the recommended locations and number of TV monitor cameras for pads 34 and 27. It was recommended that 13 cameras be located to provide coverage for both the command and service module levels, upper and lower umbilical arm and connection, service-module fuel tanks, and general pad surveillance.

A GSE-transmission system concept outline was prepared.

A study was made of various digital logic modules available. Preliminary logic diagrams were prepared for the logic to be used in the monitor and control equipment. A preliminary concept for test console was prepared.

Lists of detailed operations to be performed by the checkout computer were compiled, and flow charts and sample programs were prepared for each of the operations.

During the next period, the specifications for the checkout and maintenance equipment for the R & D instrumentation equipment will be released.

The test-control-room operations requirements and the test-conductor malfunction-routine flow chart will be released. The self-check concepts study will be continued and the results documented.

## GSE TRAINING REQUIREMENTS

Preliminary requirements for the three part-task trainers were established. Documentation of these requirements is in progress to provide a digital-computer procurement specification.

Facilities requirements for 1 trainer-mission simulator, 3 part-task trainers, and 10 system trainers were submitted.

During the next period, design layouts of the remaining 6 system trainers will be started.

Engineering and design of the part task trainers will continue.

Investigation of trainer-mission simulator requirements will continue.

## GSE ELECTRICAL DESIGN

A GSE engineering test plan which will result in a systematic approach to specified performance-and-specification characteristics was developed for the complex electronic GSE.

Six additional design or procurement specifications for telecommunications GSE will be prepared.

Design support of boilerplate 6 was a primary objective during this reporting period. As the design task for boilerplate 6 is finalized, support will be extended to future boilerplates.

Components presently identified for use in electrical design will have specification coverage and then be incorporated into an Apollo approved-components handbook. Continued effort will be made in the selection and identification of components, materials, and processes for updating of the approved-component list.

# GROUND OPERATIONAL SUPPORT SYSTEM (GOSS)

## INSTRUMENTATION

S&ID has received 95 percent of the information required to define the instrumentation system design for boilerplate 6. A coded measurement numbering system was developed and has been assigned to the measurements of boilerplate 6. Information required to define the instrumentation system design for boilerplates 12, 21, 22, and 23, is 65 percent complete.

A study was completed of the type and installation of calorimeters for boilerplates 13 and 15. Efforts to define the firm measurement and equipment requirements for boilerplates 13 and 15 will continue during the next period.

Preliminary R & D equipment procedures were completed for 60 percent of the instrumentation and subsystems of boilerplate 6.

Equipment handling procedures for Apollo R & D Government-furnished aerospace equipment were defined.

## OPERATIONAL INSTRUMENTATION

Detailed test procedures for the pressure and temperature sensors were completed. S&ID Apollo instrumentation design criteria for the environmental control system (ECS) and fuel cell systems were submitted.

A study evaluating measurement and system requirements for radiation monitoring will continue.

## AIRFRAME 001

A measurement list based on preliminary measurement requirements was completed. Preliminary specifications for instrumentation bridge power supplies were completed.

Basic criteria for procurement specifications associated with acoustic, pressure, and temperature sensors were released.

An analytical study of the effects of translunar radiation environment on photographic film used on the spacecraft was completed.

A plan of action was initiated to evaluate the crew restraint system and the shock attenuation systems and to observe anthropomorphic dummies under impact. These evaluations are scheduled for boilerplates 1 and 2. The systems consist of three high-speed cameras with timing and lighting systems capable of photographing the three dummies in two planes from start of test to roll-out of the command module after impact.

Two cameras were selected for the mission. A 70-mm pulse camera for high-resolution photography is to be used in conjuntion with the telescope. A 16-mm cine camera was selected for recording relative events.

An instrumentation system suitable for installation within the anthropomorphic dummies was designed.

Capability of magnetic tape samples to withstand hard vacuum and 100-percent oxygen environments is being determined.

Vibration and impact testing of a protective package design for tape recorders is being conducted.

# FACILITIES

## PROGRAM MANAGEMENT AND ENGINEERING AREAS

Program management, engineering, and other Apollo office areas now occupy 175,000 square feet.

The Avco "Appendix A" was submitted to NASA for approval during August.

NASA gave preliminary approval for Minneapolis-Honeywell to use their New Brighton facility in support of the Apollo Program.

In preparation for the 15 November NASA design engineering inspection, a location has been selected, and the design of this area is in process.

NASA has approved the architectural and engineering drawings to rehabilitate the assigned Northrop-Ventura facilities at El Centro and Salton Sea, California. The earth-landing-system test drops will be made at these sites. Construction should begin during the next period.

## MANUFACTURING AREAS

Facility work was started on the trainer fabrication area of Building 43 in Compton.

Purchase orders were placed for the standard autoclave, special autoclave, curing oven, and the two welding packages. These are long lead items for which advance approval was obtained in July.

Building 1 modifications (additional overhead cranes) were started during this period.

An escape tower fabrication area was activated.

Approximately 25 percent of the design of Apollo manufacturing material-handling equipment has been completed to date.

An area is being set up for fabrication of Apollo test requirements spacecraft.

The manufacturing area will be rearranged to accommodate new spacecraft tooling.

The display board technique is to reduce the hours and cost of PERT network development and maintenance. It provides a convenient display of the status of Apollo facilities.

TEST AREAS

Design of the boilerplate impact-attenuation test facility is scheduled for completion during the next quarter. Design of the facility components is also nearing completion, and fabrication has begun. Interim drop tests from a mobile crane will be conducted prior to completion at the test facility.

Studies of basic facilities for the space-bearing tests have been conducted, and selections of area, equipment and fixtures have been made. Basic vacuum equipment has been selected to support this program, and purchase orders are now being prepared for the procurement of the equipment. Both area and equipment are scheduled to be available during the next quarter.

A critical equipment-and-facilities problem exists, which must be resolved to support the development program for ordnance testing. Equipment requirements have been submitted to NASA for approval.

FACILITIES PROJECTS

Predesign site surveys have been started for the propulsion systems development facility at WSMR. Submittal of design criteria to NASA, for the propulsion systems development facility, was held up, pending new ground rules to be supplied by NASA.

Several meetings and trips were held during the report period to define the facility criteria for launch area 3 and supporting buildings at WSMR. This facility will be used for the Little Joe II mission abort tests.

Design criteria was completed for the space systems development facility. Design contracts were let, and design is in process on the following facilities:

Plaster Master
Systems integration and checkout
Bonding and test
Impact test
Radiographic
Parking

[redacted]

The design criteria for the space systems development facility and the reaction control system facility were submitted to NASA. Design criteria addenda were also submitted for the bonding, test, and systems integration and checkout facilities.

Ground work will be done for those facilities presently in design, in preparation for general contractor bidding.

Exploratory water wells will be contracted during the next period to supply the propulsion systems development facility systems at WSMR.

PERT SYSTEMS

The Apollo facilities PERT networks have been completed and approved by NASA. Biweekly reporting of facilities status has been started. A display board technique for the facilities PERT Network has been developed and installed in Apollo facilities.

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# II. MILESTONE SUMMARY

## APOLLO PROGRAM SCHEDULE STATUS

After the program redirection of 13 July 1962, NASA and S&ID representatives met to negotiate schedule and hardware requirements for the major ground- and-flight-test programs through the second manned earth-orbital flight. The results of these negotiations were reflected in S&ID Apollo Master Phasing Plan 3, dated 9 August 1962. Significant changes in this plan were as follows:

1. Deletion of boilerplate 20 - command module for pad abort test 2
2. Deletion of AFRM 007 - spacecraft for orbital entry
3. Rescheduling of all major hardware completion and launch dates. A new launch date for the first manned flight was set at 15 May 1965.

Master Phasing Plan 3 was incorporated in the ground rules for the firm cost proposal which was submitted to NASA on 30 September 1962. As this costing program progressed it became apparent that additional hardware and schedule changes would be required in order to keep program costs within funding limitations. An additional exercise was conducted to determine which hardware items could be deleted with the smallest total effect on the program objectives. This exercise resulted in publication of Master Phasing Plan 4, dated 18 September 1962 which contained the following significant changes:

1. Deletion of mock-ups 8, 16, 17, 19 and 20
2. Deletion of boilerplates 5 and 21
3. Deletion of active launch escape propulsion motor on boilerplates 13 and 15
4. Deletion of simulator 3
5. Deletion of egress trainer
6. Deletion of AFRM 012-spacecraft for second manned earth-orbital flight trainer and electrical power subsystem trainer.
7. Revision of missions for certain spacecraft. Airframe 009 now has the objective of first manned flight and is scheduled for launch on 15 December 1964.



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In Table 1, key schedule dates contained in Master Phasing Plan 4 are compared with the equivalent dates from previous phasing plans, including the plan presented in the proposal on 6 October 1961.

The Program Management Plan is currently being reviewed to ascertain the impact of the major schedule changes on the detailed development milestone requirements. An effort is under way to incorporate key events from the PERT networks into the Program Management Plan. Until these tasks have been completed, the previously developed milestone schedules will be used to determine schedule status.

Schedule status is reported in Tables 2 and 3. Table 2 lists development milestone completed during the report period. Table 3 indicates the status of key facility and hardware items required for the development program. Table 3 shows that the hardware effort is on-schedule with the exception of three mock-up items and two boilerplate items. The exceptions are discussed by hardware category in the following paragraphs:

## Mock-ups

Manufacturing completions for the following mock-ups are significantly behind schedule:

Mock-up 9 spacecraft for Handling and Transportation
Mock-up 11 spacecraft for Handling and Transportation
Mock-up 18 complete mock-up.

Mock-ups 9 and 11 have scheduled manufacturing completion dates of 5 and 12 October 1962 respectively. Progress on these mock-ups was delayed by late redesign. The completion of these mock-ups is not critical to the over-all program.

Mock-up 18 is currently 10 percent complete and is scheduled for completion in November 1962. Spacecraft design sections have been unable to support the design freeze dates for this mock-up. Information required includes crew couch configuration, blowout panel configuration, window cover configuration, MIT requirements, antenna configurations, air lock configuration and forward heat shield mechanism, and instrument panel configuration. Completion by the November completion date seems unlikely.

## Boilerplates

Two boilerplates are significantly behind schedule. The first, boilerplate 2, command module for land and water impact, is scheduled for completion on 15 December 1962. It is now 45 percent complete,

rather than the 63 percent completion scheduled. Recovery is expected and completion on schedule is anticipated.

The second behind-schedule boilerplate item is boilerplate 6, command module for pad abort. This item is scheduled for completion on 15 February 1963 and is currently three-percent complete. Scheduled completion at this time is 34 percent. This is the first hardware item requiring functional systems and, accordingly, the design has been slowed by the necessity for the first incorporation of these systems. Requirements include the launch escape system and the command module with impact attenuation system. Delays have been encountered in the definition of detailed requirements, including instrumentation. These delays have slowed the structural and detailed mechanical design effort. The most critical item appears to be lack of definition of ballast requirements. Scheduled recovery on most delinquent items is September 1962. Design release information output will be accelerated in October and the scheduled manufacturing completion date of 15 February 1963 will be met.

It should be noted that many of the problems encountered in completing the structural design of boilerplate 6 apply to other boilerplates. The successful resolution of these problems will be a positive factor in completing the design for the succeeding boilerplates.

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Table 1. Program Schedule Comparison

| Milestone | Proposal 10-6-62 | Williamsburg Negotiations 12-29-61 | Master Phasing Plans | | |
|---|---|---|---|---|---|
| | | | #1 4-25-62 | #3 8-9-62 | #4 9-18-62 |
| 100-percent design release - spacecraft | 1-15-63 | 1-1-63 | 5-1-63 | 8-15-63 | 8-15-63 |
| Manufacturing completions | | | | | |
| Dynamic test boilerplate | 5-1-63 | 10-1-62 | 9-15-62 | 1-15-63 | 1-15-63 |
| First C-1 boilerplate | 4-1-63 | 1-1-63 | 2-1-63 | 5-1-63 | 5-1-63 |
| First manned spacecraft | 9-1-63 | 11-1-63 | 2-1-64 | 7-15-64 | 3-15-64 |
| Launches | | | | | |
| First C-1 boilerplate | 7-1-63 | 7-1-63 | 6-15-63 | 11-1-63 | 11-15-63 |
| First manned spacecraft | 5-1-64 | 7-1-64 | 9-15-64 | 5-15-65 | 12-15-64 |



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Table 2. Milestone Completion Report

| General Order | Milestone Completion - Third Quarter 1962 | Scheduled Completion Date | Recorded Completion Date |
|---|---|---|---|
| 7121 | Preliminary Environmental Control Subsystem Optimization | 7-13-62 | 8-24-62 |
| 7121 | Reaction Control Subsystem - Overall Test Plan Review | 7-13-62 | 7-13-62 |
| 7121 | Receive F-86 Simulator | 7-13-62 | 7-13-62 |
| 7121 | Pad Abort Test Requirements Firm - Boilerplate No. 6 | 8-1-62 | 9-7-62 |
| 7121 | Master Propulsion Test Plan | 9-14-62 | 9-14-62 |
| 7122 | First Issue - Launch Vehicle Integration Report | 7-13-62 | 7-13-62 |
| 7122 | First Issue - Test Requirements - Boilerplate No. 19 and Boilerplate No. 2 | 8-31-62 | 8-31-62 |
| 7123 | First Failure Summary | 8-15-62 | 8-15-62 |
| 7124 | Receive Final Instrumentation Requirements List - Boilerplate No. 6 | 6-1-62 | 7-20-62 |
| 7124 | Receive Final Instrumentation Requirements List - Boilerplate No. 12 | 6-1-62 | 7-20-62 |
| 7124 | Release Approved Instrument Equipment List - Boilerplate No. 6 | 6-15-62 | 7-20-62 |
| 7124 | Instrumentation Subsystem Requirements - Boilerplate No. 1 Command Module | 7-1-62 | 7-1-62 |



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Table 2. Milestone Completion Report (Continued)

| General Order | Milestone Completion - Third Quarter 1962 | Scheduled Completion Date | Recorded Completion Date |
|---|---|---|---|
| 7124 | Instrumentation System Requirements Boilerplate No. 3 | 7-15-62 | 8-1-62 |
| 7124 | Instrumentation Subsystem Requirements Boilerplate No. 19 Command Module | 7-15-62 | 8-1-62 |
| 7128 | Flight Operations Manual | 7-2-62 | 7-2-62 |
| 7130 | Boilerplate No. 16 Control Systems Requirements | 9-7-62 | 9-14-62 |
| 7132 | 100 Percent Launch Escape System Structure Design Release - Boilerplate No. 9 | 6-1-62 | 7-6-62 |
| 7132 | 100 Percent Release Launch Escape System Development Motor Design Release | 7-20-62 | 8-20-62 |
| 7132 | Launch Escape System Drawing Release | 7-20-62 | 8-20-62 |
| 7133 | Select Supplier Critical Gas Storage System | 6-8-62 | 8-17-62 |
| 7133 | Equipment Specs AiResearch Components | 9-15-62 | 9-14-62 |
| 7134 | 100 Percent Installation Design Release - Earth Landing System | 4-27-62 | 7-6-62 |
| 7134 | Boilerplate No. 3 System Evaluation and Test Plan | 8-1-62 | 8-1-62 |
| 7135 | Interim Results of Communications Studies | 6-22-62 | 7-13-62 |



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Table 2. Milestone Completion Report (Continued)

| General Order | Milestone Completion - Third Quarter 1962 | Scheduled Completion Date | Recorded Completion Date |
|---|---|---|---|
| 7136 | Control and Display Requirements | 8-3-62 | 8-28-62 |
| 7137 | Complete Assembly and Installation Drawings Boilerplate No. 1 | 5-11-62 | 7-6-62 |
| 7137 | Complete Structural Assembly Boilerplate No. 1 Command Module | 5-25-62 | 8-24-62 |
| 7137 | Complete Structural Assembly Boilerplate No. 3 Command Module | 6-8-62 | 7-7-62 |
| 7137 | Complete Structural Assembly and Installation Dwg - Boilerplate No. 3 | 6-29-62 | 7-6-62 |
| 7137 | Complete Assembly and Installation Drawings - Boilerplate No. 3 | 6-29-62 | 7-6-62 |
| 7137 | Complete Assembly and Installation Drawings - Boilerplate No. 9 | 7-13-62 | 8-31-62 |
| 7137 | Complete Command Module Assembly and Installation Drawings - Boilerplate No. 19 | 8-3-62 | 8-17-62 |
| 7137 | Complete Command Module Drawings | 8-3-62 | 8-17-62 |
| 7137 | 100 Percent Design Release - Boilerplate No. 9 | 8-3-62 | 8-31-62 |
| 7137 | Installation of Dummy Supports - Command Module Boilerplate No. 1 | 8-15-62 | 9-7-62 |
| 7137 | Installation and Checkout - Boilerplate No. 1 | 9-7-62 | 9-7-62 |
| 7137 | Dynamic Pressure Test | 9-7-62 | 9-7-62 |

Table 2. Milestone Completion Report (Continued)

| General Order | Milestone Completion - Third Quarter 1962 | Scheduled Completion Date | Recorded Completion Date |
|---|---|---|---|
| 7138 | System Test Requirements Finalized - Service Propulsion System | 9-1-62 | 9-1-62 |
| 7139 | 100 Percent Design Release - Boilerplate No. 9 and Initial Flight Articles Service Module | 6-29-62 | 7-6-62 |
| 7142 | 100 Percent Design Release - Adapter - Boilerplate No. 13 | 9-14-62 | 9-14-62 |
| 7143 | 100 Percent GSE Drawing Release - Boilerplate No. 1 | 3-16-62 | 9-14-62 |
| 7143 | 100 Percent GSE Drawing Release - Boilerplate No. 3 | 3-16-62 | 9-14-62 |
| 7143 | 100 Percent GSE Drawing Release - Boilerplate No. 2 | 3-16-62 | 9-14-62 |
| 7143 | 100 Percent GSE Drawing Release - Boilerplate No. 19 | 4-13-62 | 9-14-62 |
| 7143 | Start Delivery GSE Interface | 7-2-62 | 7-2-62 |

Table 3. Apollo Schedule Position (as of 21 September 1962)

| Item Description | Schedule | | Percent Completion | | Remarks |
|---|---|---|---|---|---|
| | Start | Finish | Sched | Actual | |
| Facilities: | | | | | |
| Propulsion development | 3-1-62 | 2-20-64 | | | On schedule |
| Integration and checkout | 3-1-62 | 10-29-63 | | | On schedule |
| Space systems development | 4-6-62 | 10-11-63 | | | On schedule |
| Bonding test | 3-1-62 | 5-27-63 | | | On schedule |
| Data ground station | 4-30-62 | 5-3-63 | | | On schedule |
| Impact test | 4-13-62 | 12-12-62 | | | On schedule |
| Radiographic | 4-13-62 | 2-22-63 | | | 4 weeks behind schedule |
| Engineering design release: | | | | | |
| Mock-ups | | | | | |
| M-2 Cabin interior arrangement | 2-9-62 | 6-1-62 | 100 | 100 | |
| M-3 Cabin interior arrangement | 2-23-62 | 6-1-62 | 100 | 100 | |
| M-4 Service module and adapter interface | 3-2-62 | 6-1-62 | 100 | 100 | |
| M-5 Cabin exterior equipment | 3-2-62 | 6-1-62 | 100 | 100 | |
| M-7 Complete service module | 3-30-62 | 6-1-62 | 100 | 100 | |
| M-9 Spacecraft handling and transportation | 3-30-62 | 7-27-62 | 100 | 100 | |
| M-11 Spacecraft handling and transportation | 3-30-62 | 8-17-62 | 100 | 100 | |
| M-12 Crew support system | 5-25-62 | 8-17-62 | 100 | 100 | |
| M-18 Complete mock-up | 6-22-62 | 9-21-62 | 100 | 33 | |
| Boilerplates | | | | | |
| B-1 Command module for land and water impact | 3-2-62 | 8-17-62 | 78 | 75 | |
| B-2 Command module for land and water impact | 2-23-62 | 8-31-62 | 76 | 76 | |
| B-3 Command module for parachute recovery | 3-9-62 | 9-28-62 | 93 | 88 | |
| B-19 Command module for parachute recovery | 3-9-62 | 9-28-62 | 93 | 88 | |
| B-9 Spacecraft for dynamic tests | 5-11-62 | 10-5-62 | 78 | 95 | |
| B-6 Command module for pad abort | 5-4-62 | 10-5-62 | 89 | 76 | |
| B-12 Command module for max "q" launch escape system verification (LJII) | 5-4-62 | 11-30-62 | 77 | 62 | |
| B-13 First orbital spacecraft for booster compat | 3-30-62 | 2-22-63 | 49 | 49 | |

## Table 3. Apollo Schedule Position (Cont'd)

| Item Description | Schedule | | Percent Completion | | Remarks |
|---|---|---|---|---|---|
| | Start | Finish | Sched | Actual | |
| Engineering design release: | | | | | |
| Boilerplates | | | | | |
| B-14 House spacecraft No. 1 | 6-1-62 | 4-26-63 | 22 | 13 | |
| B-15 Dummy spacecraft | 5-11-62 | 2-1-62 | 45 | 48 | |
| B-16 Dummy spacecraft | 5-11-62 | 5-10-63 | 26 | 25 | |
| B-18 Dummy spacecraft | 5-11-62 | 6-28-63 | 24 | 23 | |
| B-22 Hi-alt-flight abort (LJII) | 5-11-62 | 3-1-63 | 53 | 47 | |
| B-23 Back-up for B-6, B-12 | 5-11-62 | 12-28-62 | 73 | 59 | |
| B-25 Command module for water recovery and handling equip | 6-8-62 | 6-22-62 | 100 | 100 | |
| Spacecraft | | | | | |
| 001 Propulsion system qualification | 6-1-62 | 7-5-63 | 13 | 7 | |
| 002 Command module for max q launch escape system verification (LJII) | 6-1-62 | 5-10-63 | 10 | 6 | |
| 004 Spacecraft for static test No. 1 | 6-1-62 | 5-10-63 | 15 | 9 | |
| 005 Command module for static test No. 2 | 6-1-62 | 5-10-63 | 23 | 13 | |
| 006 House spacecraft No. 2 and back-up for 008 | 6-1-62 | 10-18-63 | 11 | 6 | |
| 008 Spacecraft for environmental proof | 6-1-62 | 9-20-63 | 11 | 6 | |
| 009 Spacecraft for first manned flight | 6-1-62 | 8-2-63 | 14 | 8 | |
| 010 Command module for pad abort | 6-1-62 | 11-8-63 | 11 | 6 | |
| 011 Spacecraft for second manned flight | 6-1-62 | 11-29-63 | 11 | 6 | |
| Manufacturing completions: | | | | | |
| Mockups | | | | | |
| M-2 Cabin interior arrangement | 5-4-62 | 10-19-62 | 80 | 80 | Rescheduled |
| M-3 Cabin interior arrangement | 3-2-62 | 6-8-62 | 100 | 100 | |
| M-4 Service module and adapter interface | 2-23-62 | 6-8-62 | 100 | 100 | |
| M-5 Cabin exterior equipment | 3-2-62 | 6-8-62 | 100 | 100 | |
| M-7 Complete Service module | 3-30-62 | 6-15-62 | 100 | 100 | |
| M-9 Spacecraft handling and transportation | 5-11-62 | 10-5-62 | 95 | 66 | |

## Table 3. Apollo Schedule Position (Cont'd)

| Item Description | Schedule | | Percent Completion | | Remarks |
|---|---|---|---|---|---|
| | Start | Finish | Sched | Actual | |
| Manufacturing completions: | | | | | |
| Mockups | | | | | |
| M-11 Spacecraft handling and transportation | 5-11-62 | 10-12-62 | 90 | 50 | |
| M-12 Crew support system | 5-25-62 | 9-28-62 | 97 | 88 | |
| M-18 Complete mockup | 6-22-62 | 11-9-62 | 65 | 10 | |
| Boilerplates | | | | | |
| B-1 Command module for land and water impact | 3-1-62 | 10-1-62 | 100 | 100 | |
| B-2 Command module for land and water impact | 6-22-62 | 12-15-62 | 63 | 45 | |
| B-3 Command module for parachute recovery | 5-1-62 | 11-23-62 | 87 | 88 | |
| B-6 Command module for pad abort | 8-10-62 | 2-15-63 | 34 | 3 | |
| B-9 Spacecraft for dynamic tests | 8-31-62 | 1-15-63 | 4 | 4 | |
| B-12 Command module for max q launch escape system verification (LJII) | 10-1-62 | 4-1-63 | 2 | 2 | |
| B-13 First orbital spacecraft for booster compat | 10-15-62 | 5-1-63 | 2 | 2 | |
| B-14 House spacecraft No. 1 | 10-15-62 | 5-15-63 | | | Not due in-work |
| B-15 Dummy spacecraft | 1-15-63 | 8-1-63 | | | Not due in-work |
| B-16 Dummy spacecraft | 6-1-63 | 12-1-63 | | | Not due in-work |
| B-18 Dummy spacecraft | 8-1-63 | 2-1-64 | | | |
| B-19 Command module for parachute recovery | 6-1-62 | 12-21-62 | 55 | 71 | |
| B-22 Hi-alt flight abort (LJII) | 2-21-63 | 11-1-63 | | | Not due in-work |
| B-23 Backup for B-6 and B-12 | 11-15-62 | 6-1-63 | | | Not due in-work |
| B-25 Command module for water recovery and handling equip | 6-8-62 | 7-31-62 | 100 | 100 | |
| Spacecraft | | | | | |
| None due in-work | | | | | |

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# III. ANALYSIS DATA

FLIGHT TECHNOLOGY

## WIND TUNNEL PROGRAM

### Program Status

The current status of the wind tunnel program and planned activities for the next reporting period are summarized in Figure 1. The scale of models currently in work and the degree of completion of design and fabrications are indicated. The objectives and status of the test and related reports are also shown.

### Command Module Static Stability Tests

Hypervelocity force tests of the entry vehicle were conducted in the Arnold Engineering Development Center (AEDC) Hot Shot II tunnel at Mach number 18.5 and in the Cornell Aeronautical Laboratory (CAL) shock tunnel at Mach number 15.8. Data from these tests have been compared with Newtonian theory predictions and data from previous continuous flow tunnel tests of the FS-3 model at Mach number 6 and the FS-1 model at Mach number 9. The data compare favorably with the possible exception of the CAL shock tunnel data at angles of attack of 0 to 50 degrees and 140 to 180 degrees. Significant differences in the force coefficients were noticed with regard to position of the model in the test section, and the data are being studied to determine if model position accounts for all of the discrepancies indicated by the data comparison.

Tests of the entry vehicle with the parachute cover removed were completed in the NAAL tunnel. Data were obtained at low subsonic Mach numbers. The 0.105-scale FS-9 model installed in the NAAL tunnel is shown in Figure 2. The data from this model did not differ significantly from data obtained with a complete command module.

Command module aerodynamic characteristics were obtained with a half-span model FS-3A in the AEDC A tunnel at Mach number 3. Several conventional full-round models are required to avoid sting effects when measuring force data through a complete 180 degree angle of attack range. Successful use of the half-span technique would greatly simplify model construction and would provide more efficient tunnel utilization. Half-span model results are compared with full-round model data in Figure 3. The disagreement in data is believed to be due to separation of the reflection

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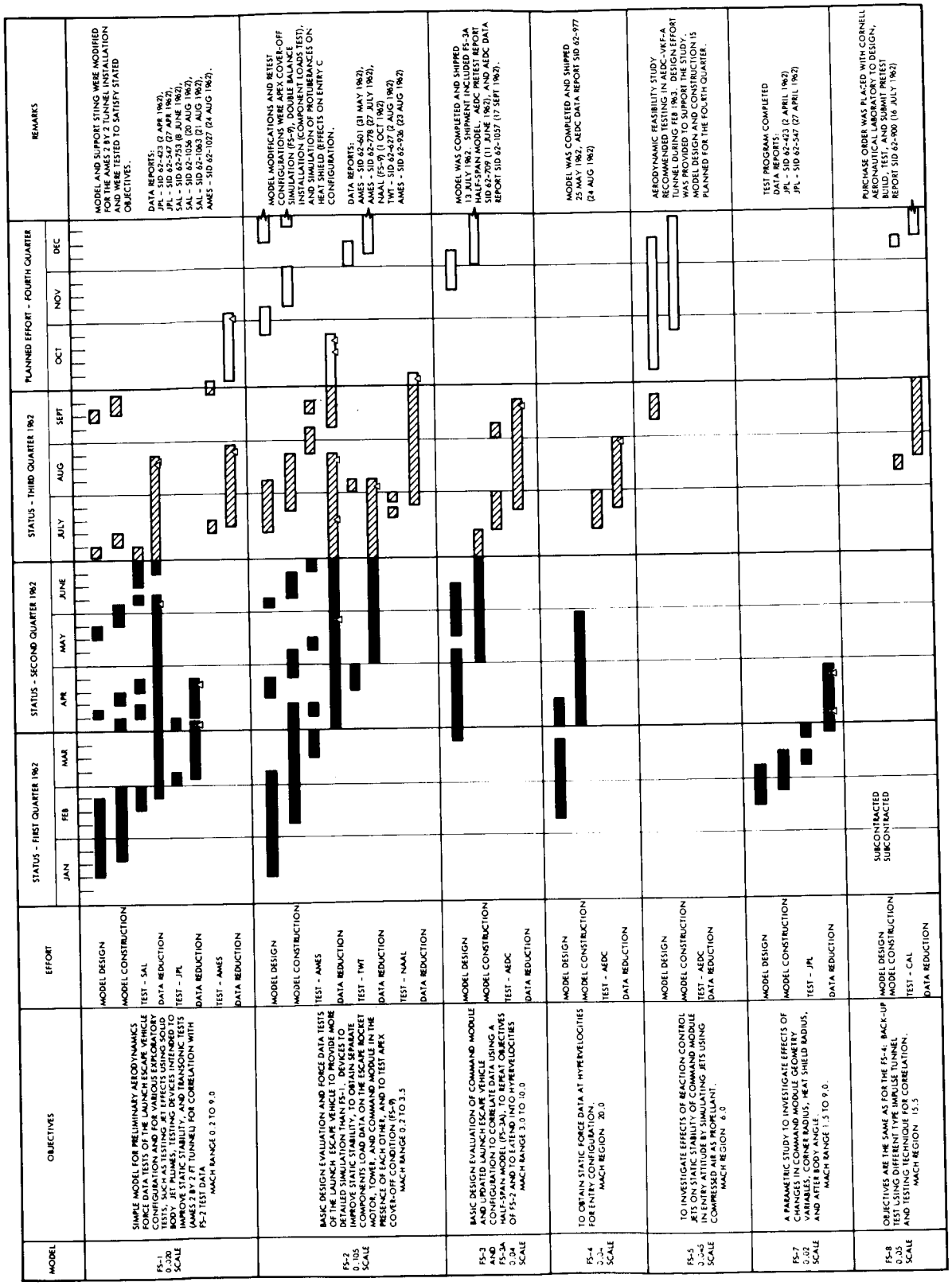


Figure 1. Apollo Wind Tunnel Program Status Summary (Sheet 1 of 4)



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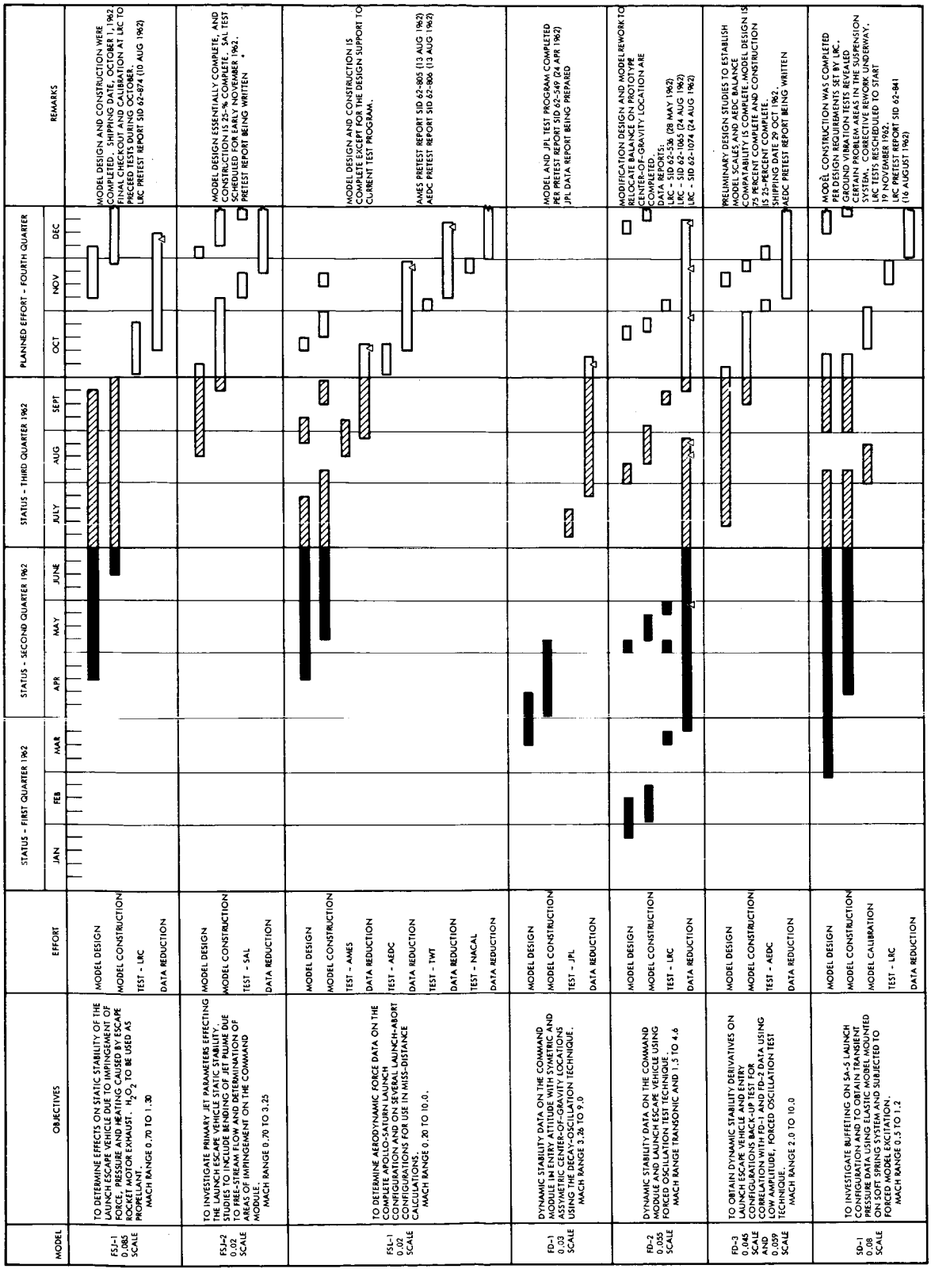


Figure 1. Apollo Wind Tunnel Program Status Summary (Sheet 2 of 4)



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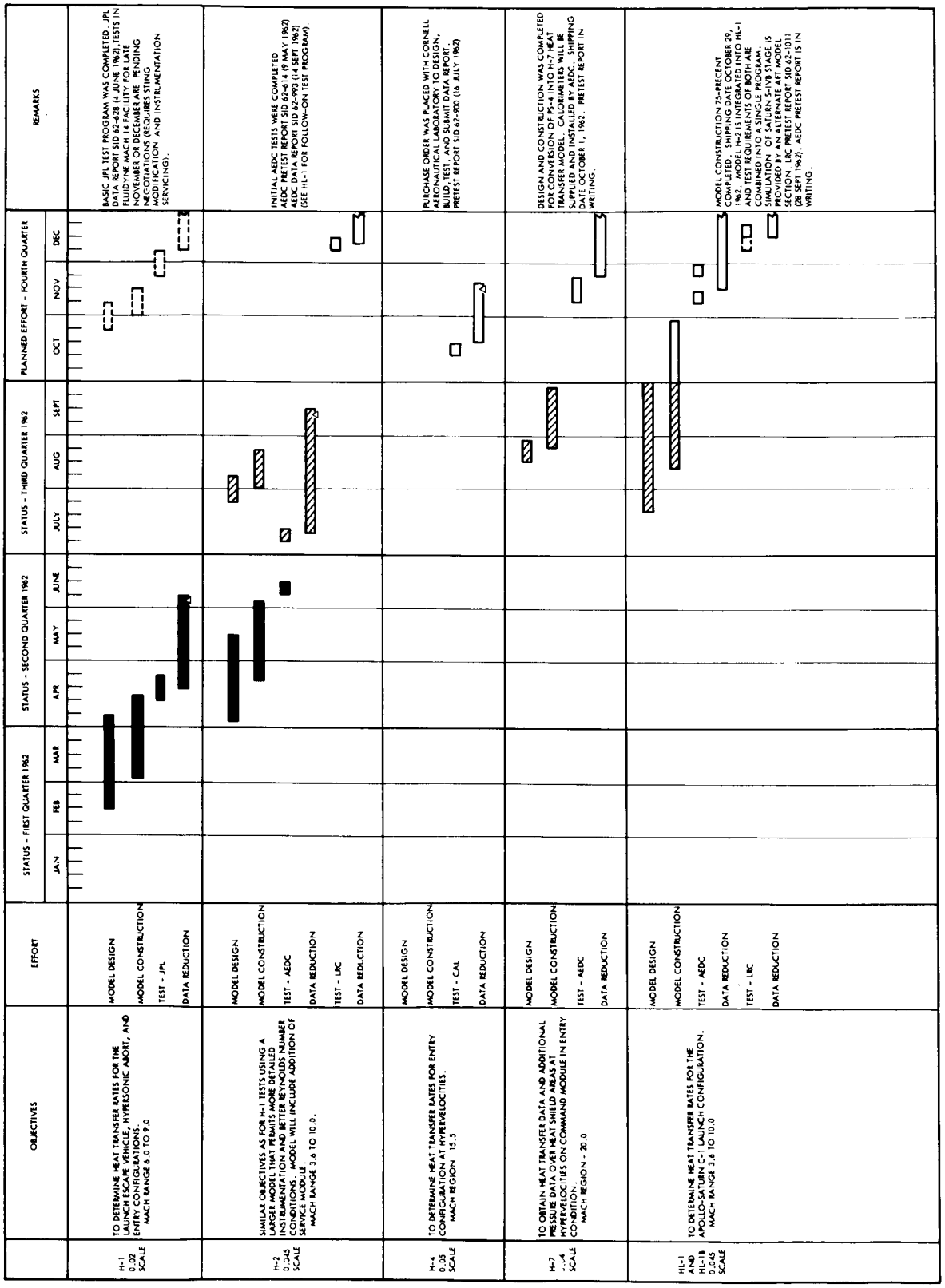


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Figure 1. Apollo Wind Tunnel Program Status Summary (Sheet 3 of 4)

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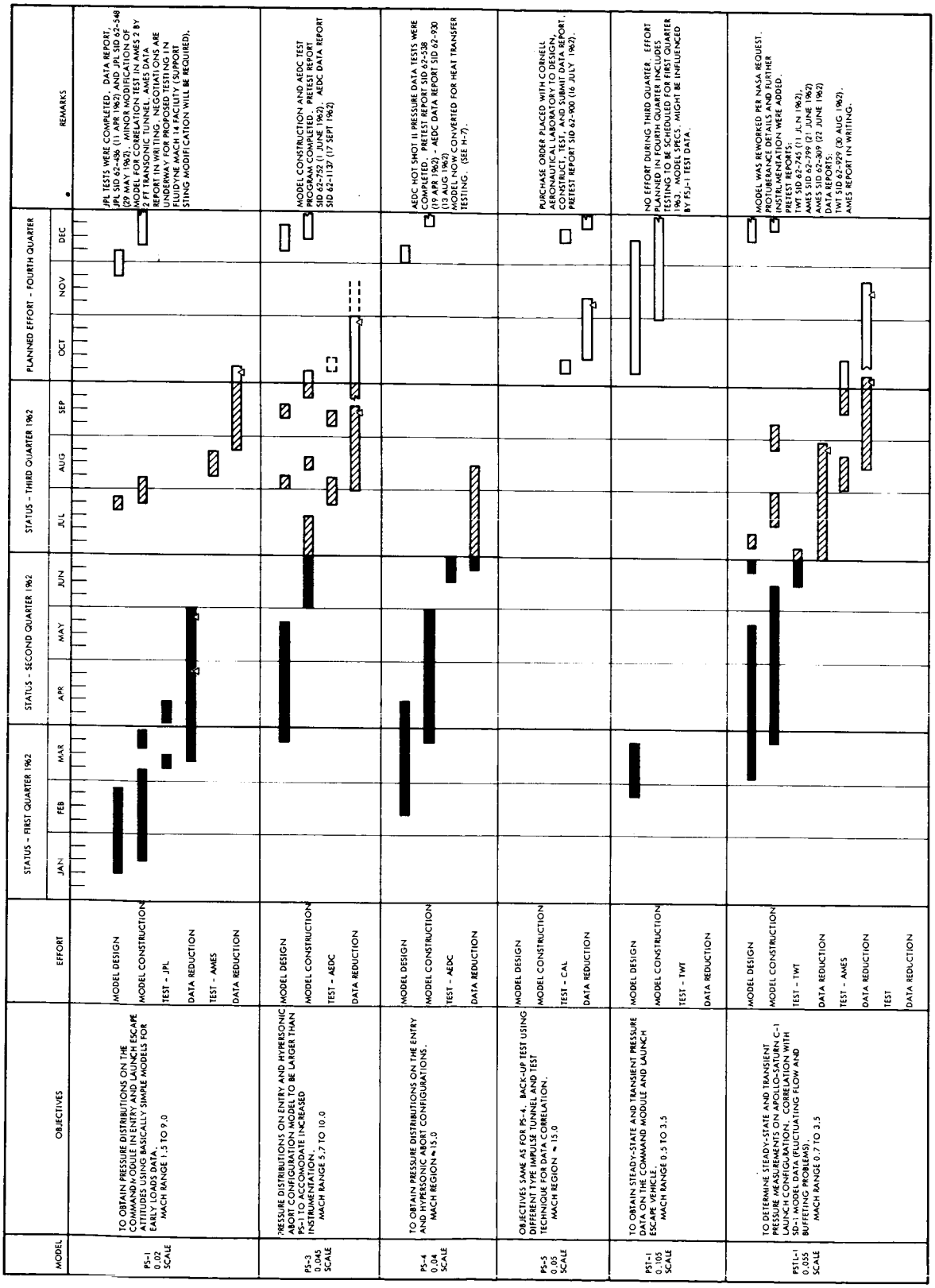


Figure 1. Apollo Wind Tunnel Program Status Summary (Sheet 4 of 4)



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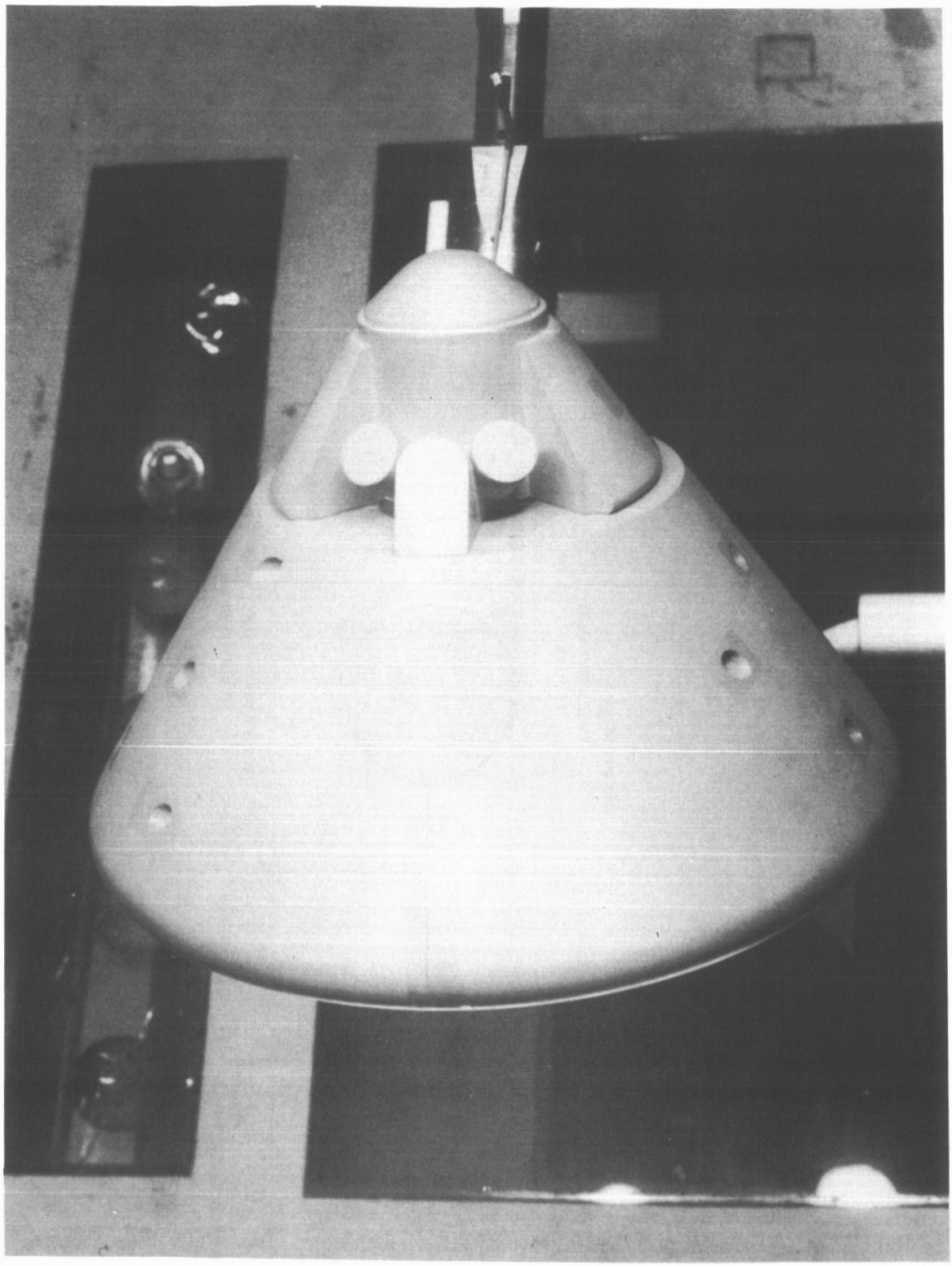

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Figure 2. FS-9 0.105-Scale Model Installed in the North American Aviation Laboratory Wind Tunnel

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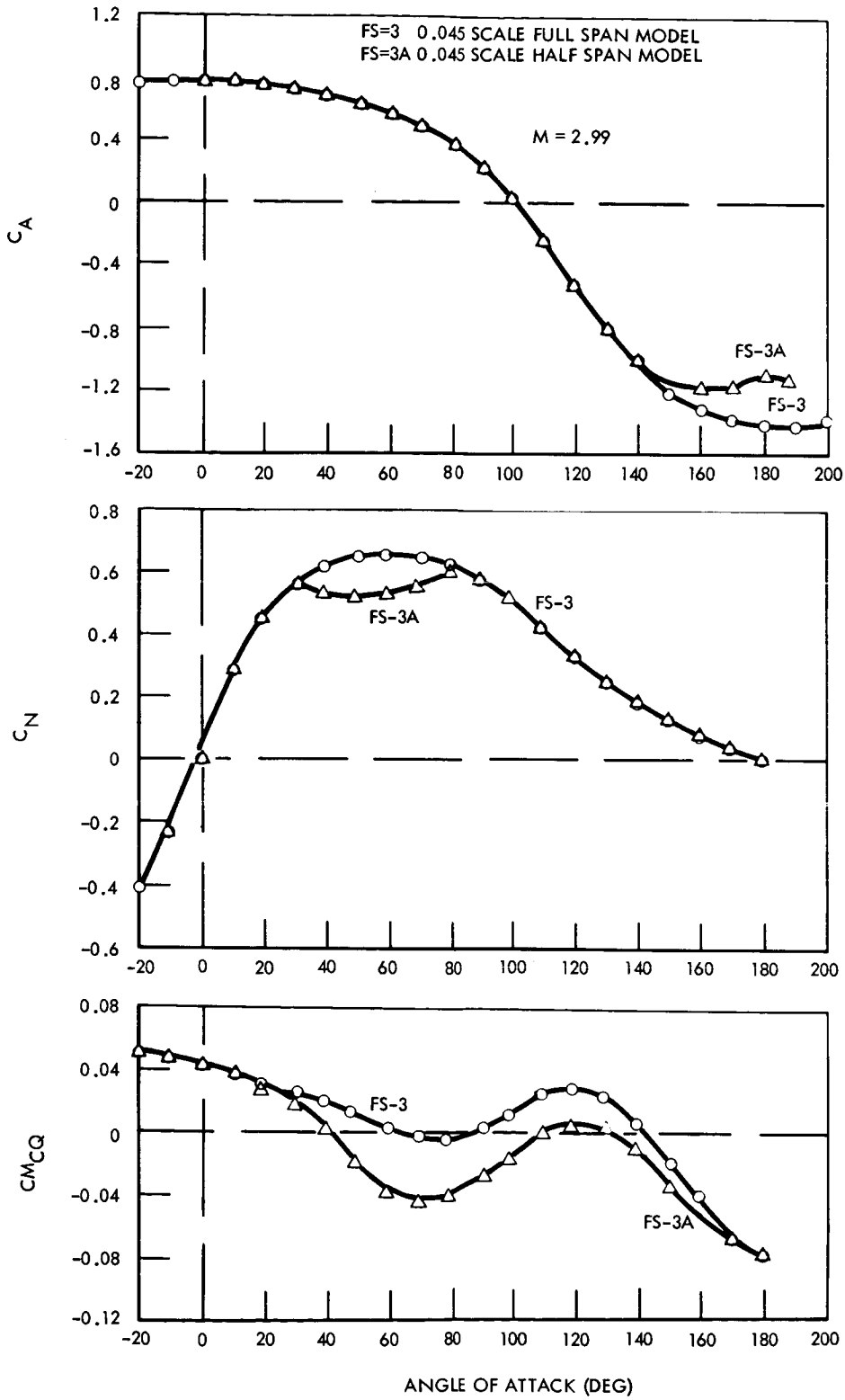


Figure 3. Half-Span Model Test Results



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plane boundary layer caused by the strong shock waves generated by the command module. Further development of the half-span technique is required before adequate results can be obtained with the Apollo configuration.

Launch Escape Vehicle Component Loads Model

Tests of the 0.105-scale FS-2 component loads model have been completed in the Ames Unitary Plan Wind Tunnel. The FS-2 model was modified to include a secondary balance between the escape motor and the tower to isolate the forces on the escape motor. The model was constructed so that the loads in the motor, the tower, and the command module could be measured separately. Figure 4 presents some typical test results obtained at Mach number 1.55. Data from these tests will be used to supplement analytical calculations of Apollo vehicle component design loads.

Hydrogen Peroxide Hot Jet Simulation

Model design and construction were completed on the FSJ-1 model to be tested in the Langley 16-foot transonic tunnel in October.

Revisions to the prototype launch escape motor required several changes in the FSJ-1 model design. The total thrust vector was realigned by differential nozzle throat sizes in the pitch plane rather than by pitching all nozzles an equal amount. The model is provided with several nozzles to investigate the effect of cant angle (angle between nozzle centerline and motor centerline).

The launch escape motor thrust has also been revised to a lower level with a different thrust-time history. Thrust is varied in the model by changing chamber pressure through metering the hydrogen peroxide propellant.

Pressure orifices and thermocouples have been installed on the command module to determine the effects of motor operation on the module pressure distribution and the areas of jet impingement.

Parachute Recovery System Wind Tunnel Program

A wind tunnel program has been formulated to investigate the aerodynamic characteristics of the drogue chute alone and the drogue chute with the command module. Static and dynamic stability characteristics are to be determined in tests in the NAAL tunnel, the Ames 12-foot pressure tunnel, and the Langley spin tunnel. S&ID is awaiting NASA approval of this program.

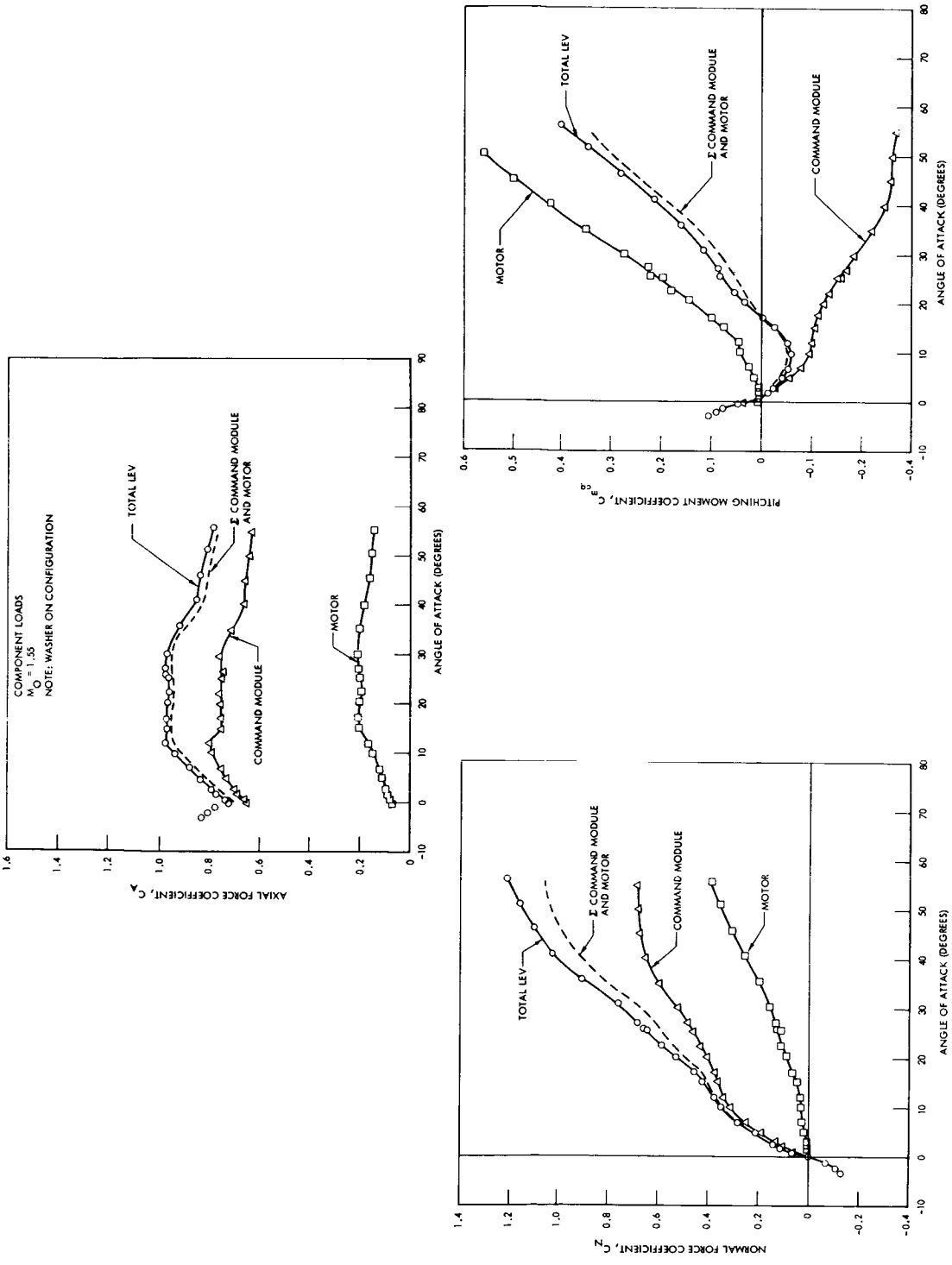


Figure 4. Axial Force Coefficient Versus Angle of Attack

Boost Flight System - Structural Dynamics Model

The 0.080-scale SD-1 structural dynamics model was completed, and model damping calibrations were initiated. The model installed in the dynamic calibrations rig is shown in Figure 5. During these calibration tests, it was noted that the mode shapes of the model were significantly different from original estimates used to design the model. Consequently, the mechanical damping of the model suspension system produced unacceptable model damping characteristics. Redesign and rework of the model support system is under way, and ground vibration tests have been rescheduled as shown in Figure 1.

Ballistic Range Tests

To evaluate the feasibility of applying ballistic range testing techniques to the Apollo experimental aerodynamics program, facility survey trips were made to the Naval Ordnance Laboratory, Silver Spring, Maryland; the Ballistic Research Laboratories (BRL), Aberdeen Proving Ground, Maryland; and the Canadian Armament Research and Development Establishment (CARDE), Quebec, Canada. Methods for testing the command module and launch escape vehicle for aerodynamic stability (static and dynamic) and heat transfer data were primarily discussed.

Transonic drag and stability data for the command module can be readily acquired at BRL, and negotiations are under way to install a test program in the BRL transonic range. Gathering of similar data for the launch escape vehicle presents problems resulting from high acceleration loads during the launching of a model configuration of marginal structural rigidity. In addition to investigating the feasibility of launch escape vehicle testing at their facility, CARDE indicated that they would fire several rounds of the command module configuration to determine the applicability of "yaw card" techniques to blunt body test data.

CARDE was asked to investigate the possibility of testing the launch escape vehicle with a live launch escape motor. Preliminary replies indicate that this test could be performed, but not without a certain amount of development effort.

AERODYNAMICS

Entry Flight System

The hypersonic lift-to-drag characteristics of the command module are shown in Figure 6. Trim angle of attack is determined by the center-of-gravity location, and the figure illustrates the effect of center-of-gravity change on the trim lift-to-drag ratio. For the nominal center-of-gravity

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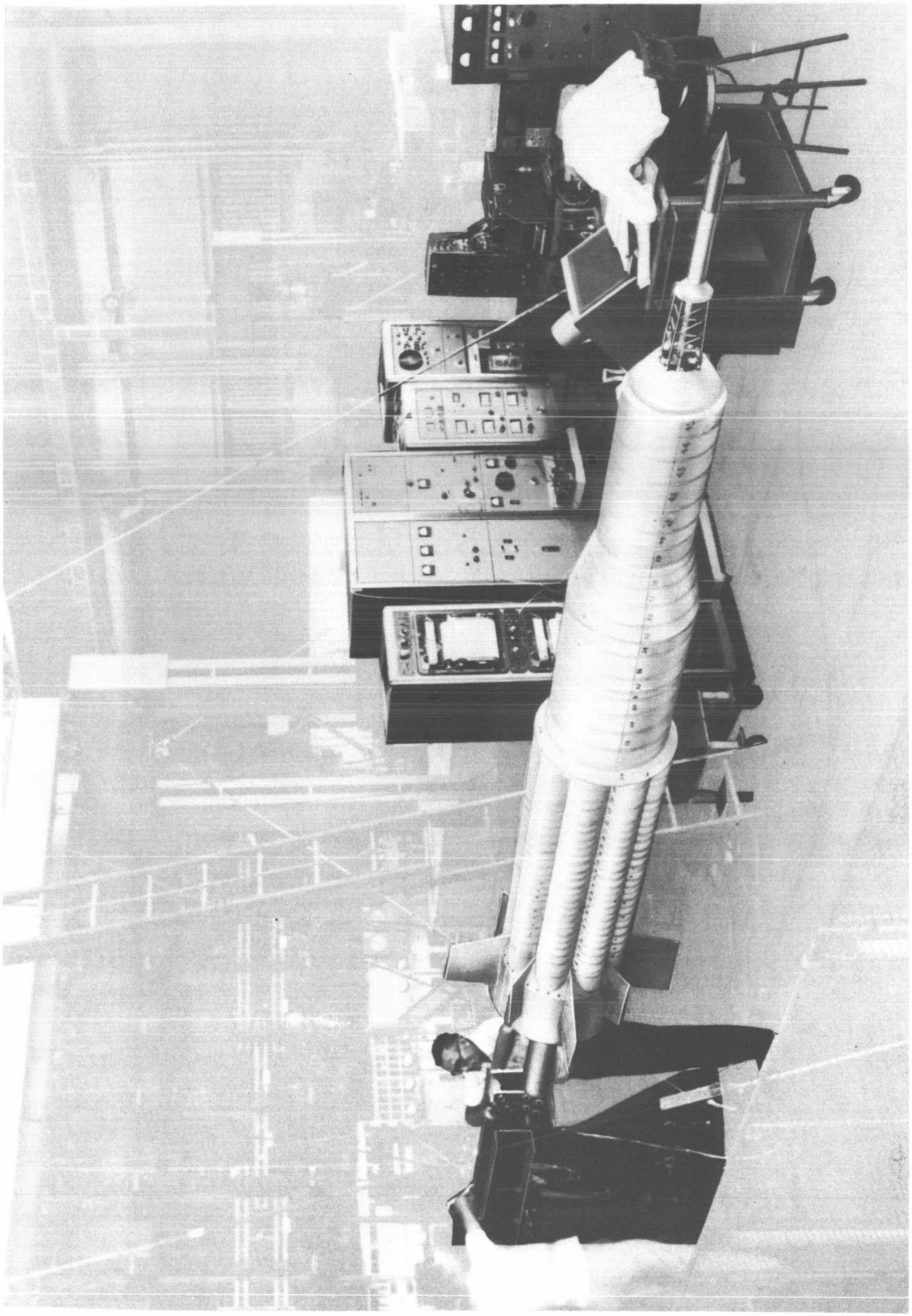

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Figure 5. 0.080 Scale SD-1 Structural Dynamics Model Installed in Calibration Rig



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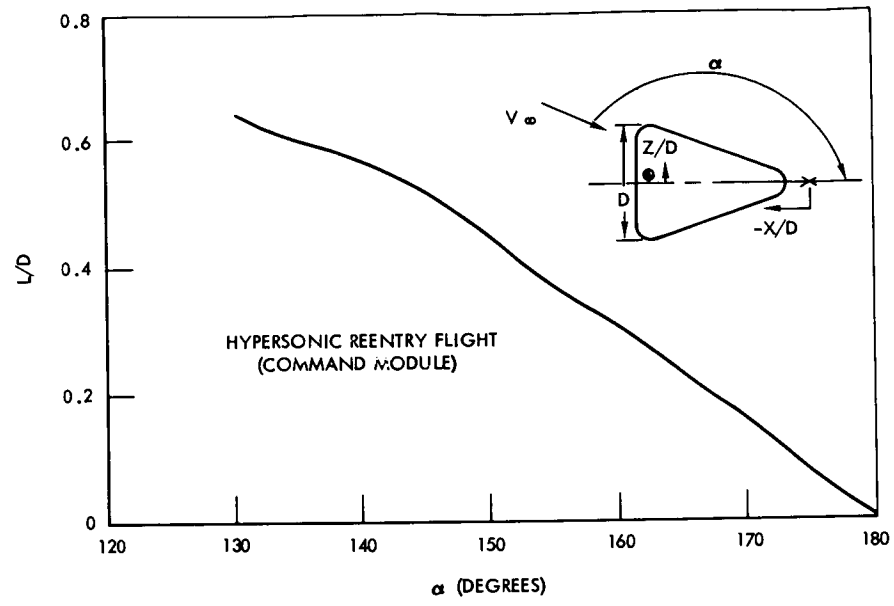


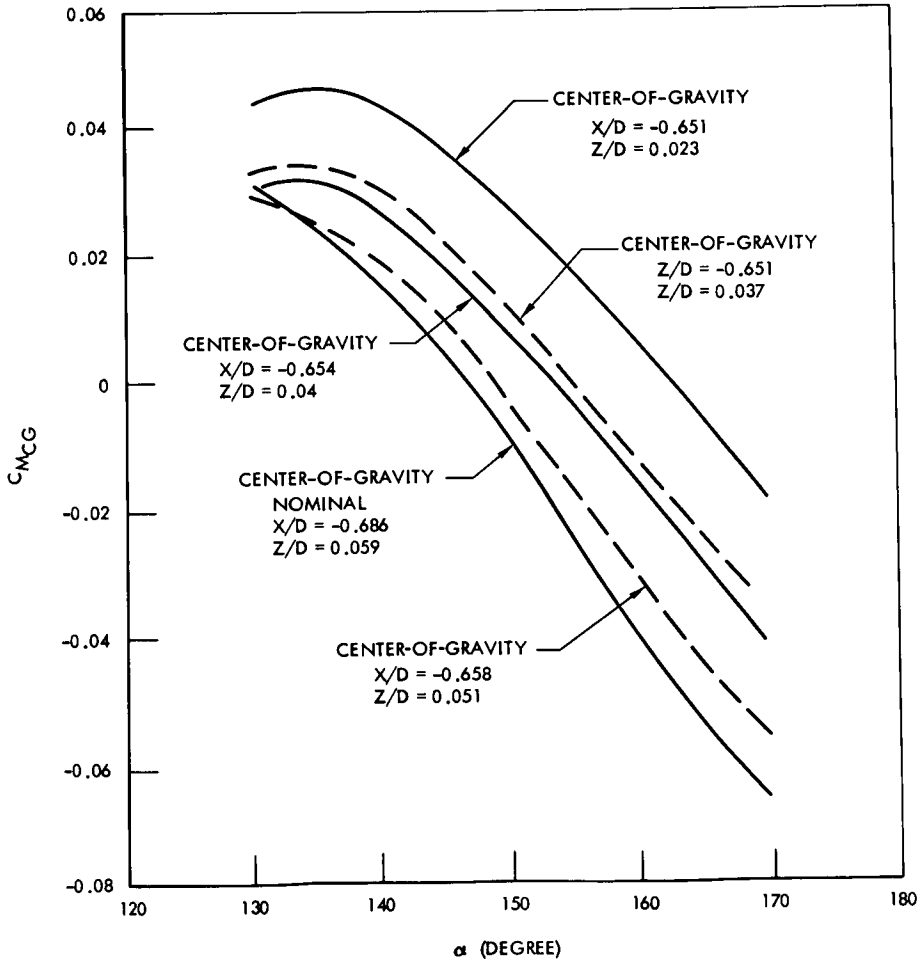


Figure 6. Pitching Moment and Trim Characteristics With Variation of Center of Gravity

location, the trim lift-to-drag ratio is 0.50. Movement of the center of gravity away from the heat shield and toward the axis of symmetry will result in an increased trim angle of attack and a reduced trim lift-to-drag ratio. Lift-to-drag ratio is affected more noticeably by a change in the offset center-of-gravity dimension than by a corresponding change in the longitudinal position. For the present center-of-gravity location, trim angle of attack on entry is about 162 degrees. This corresponds to a lift-to-drag ratio of 0.28. Studies are in progress to restore the entry lift-to-drag ratio to 0.50.

Possible corrections include the addition of ballast to provide an acceptable center of gravity, or the altering of the external shape of the body to restore the lift-to-drag ratio.

One solution that has been suggested is the addition of a flap, such as that shown in Figure 7. Flap effectiveness was estimated by modified Newtonian theory and was verified by the test data contained in NASA TWX-579. A flap size of length-to-diameter ratio equal to 0.057 is presently required to trim at 147 degrees angle of attack (lift-to-drag ratio = 0.5). Wind tunnel tests are planned to determine the optimum flap size and geometry required. Elimination of the apex-forward trim condition is another problem under consideration. By eliminating this trim point, drogue chute requirements may be greatly reduced resulting in increased reliability and decreased weight. The destabilizing effectiveness (apex forward) of narrow lifting surfaces mounted near the apex of the command module is being analyzed. Limited supersonic data are available for a configuration similar to one under consideration, and favorable trends are predicted (Figure 8). These data were obtained in tests of the 0.105-scale FS-2 model in the Ames Unitary Plan Wind Tunnel. Additional wind tunnel test results are required to verify the feasibility of this proposed solution. Other solutions being studied include the addition of fixed or stowable surfaces and modifications to the shape of the apex.

Figure 9 summarizes preliminary aerodynamic damping characteristics of the command module. The data were obtained from a series of forced oscillation dynamic stability wind tunnel tests conducted at the Langley Unitary Plan Wind Tunnels and the Langley 8-foot transonic pressure tunnel. These data indicate that unstable damping occurs at subsonic Mach numbers. However, the results are considered preliminary because the test center of gravity (center of rotation) was not consistent with the design center of gravity because of physical limitations in model and balance design. Methods are being developed to transfer the data from the test center-of-gravity location to the design center of gravity. The trend shown in Figure 8 is believed valid, but the levels are uncertain.

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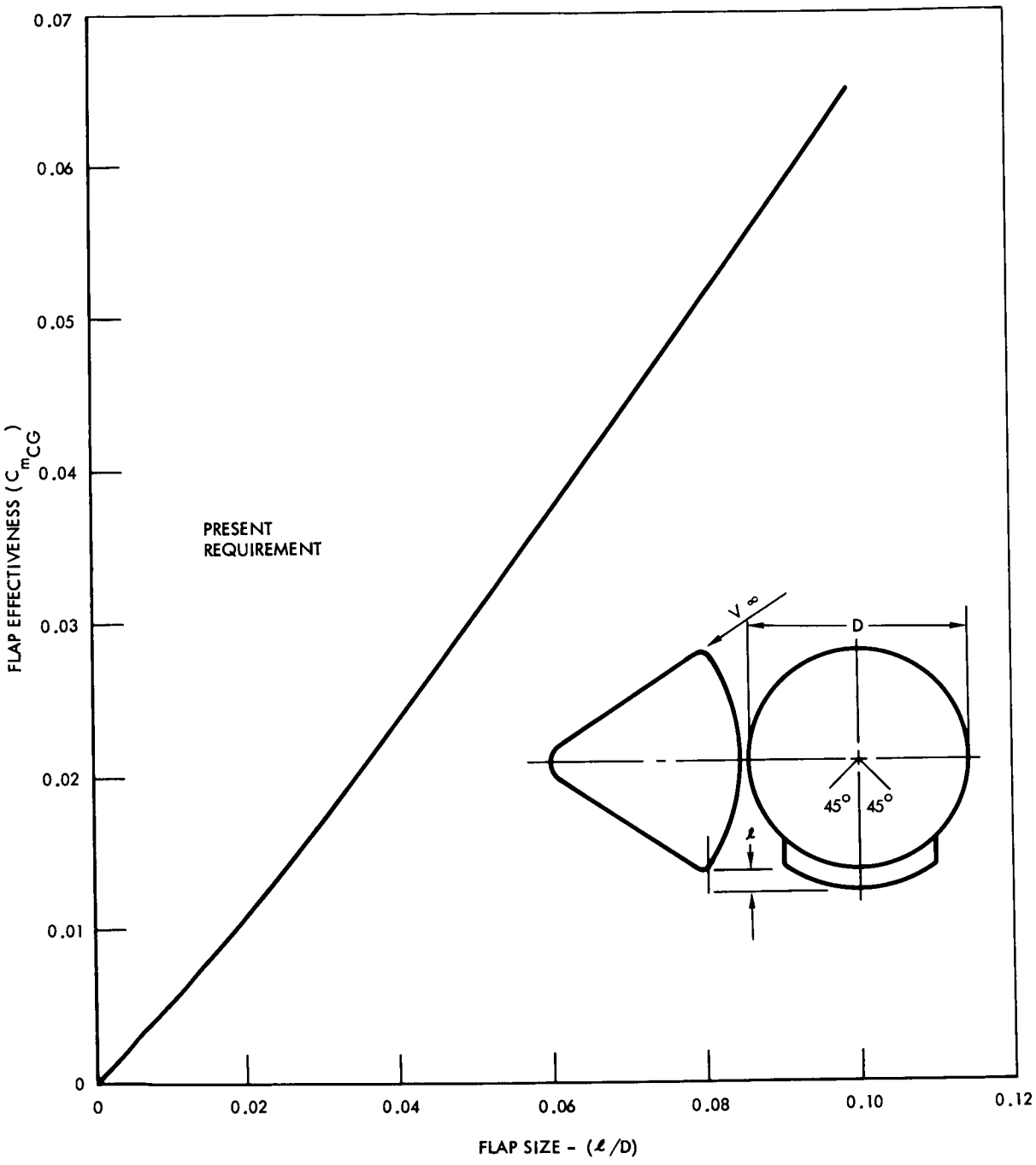


Figure 7. Flap Effectiveness at 147 Degrees Angle of Attack

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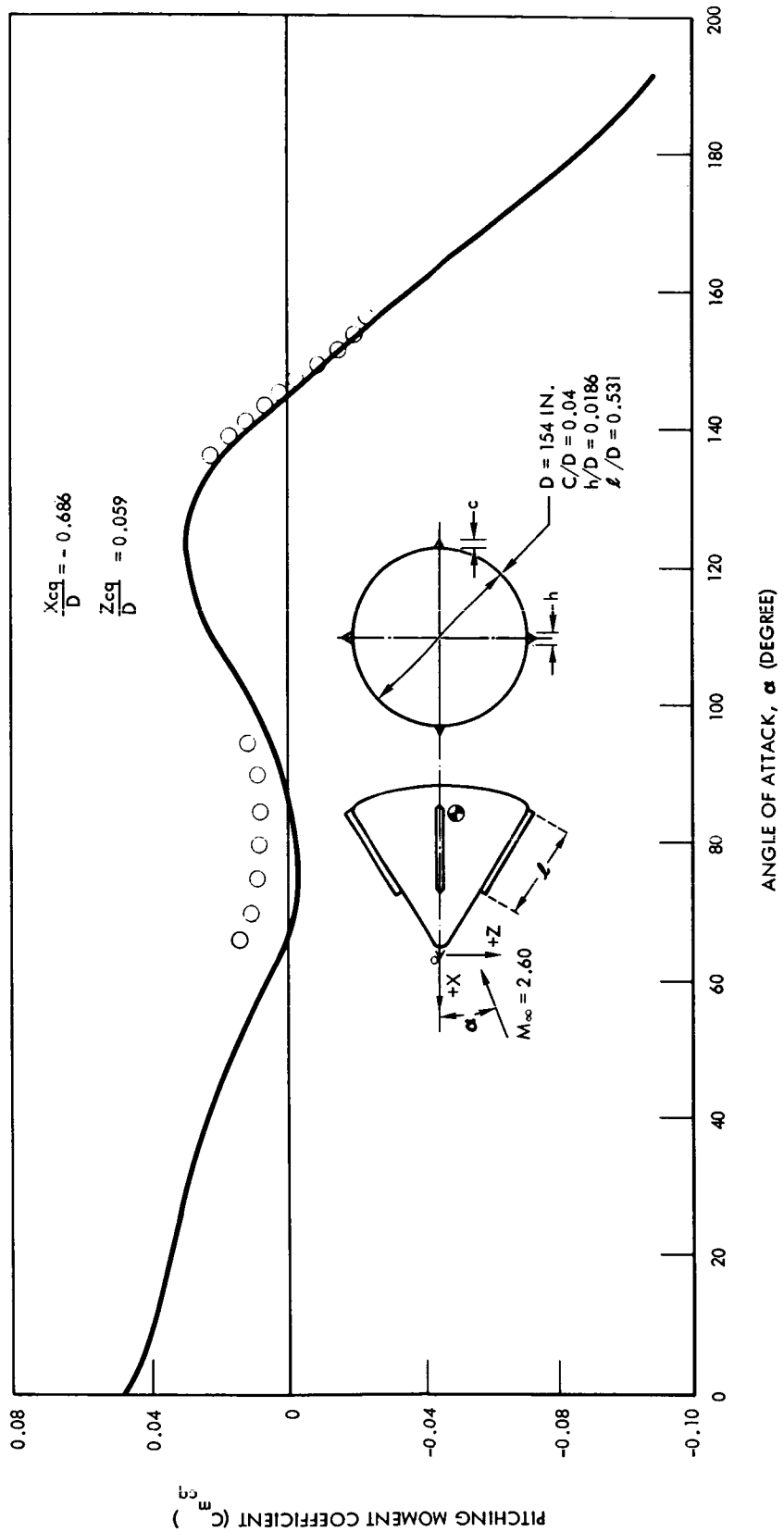


Figure 8. Variation of Pitching Moment With Angle of Attack at M = 2.60

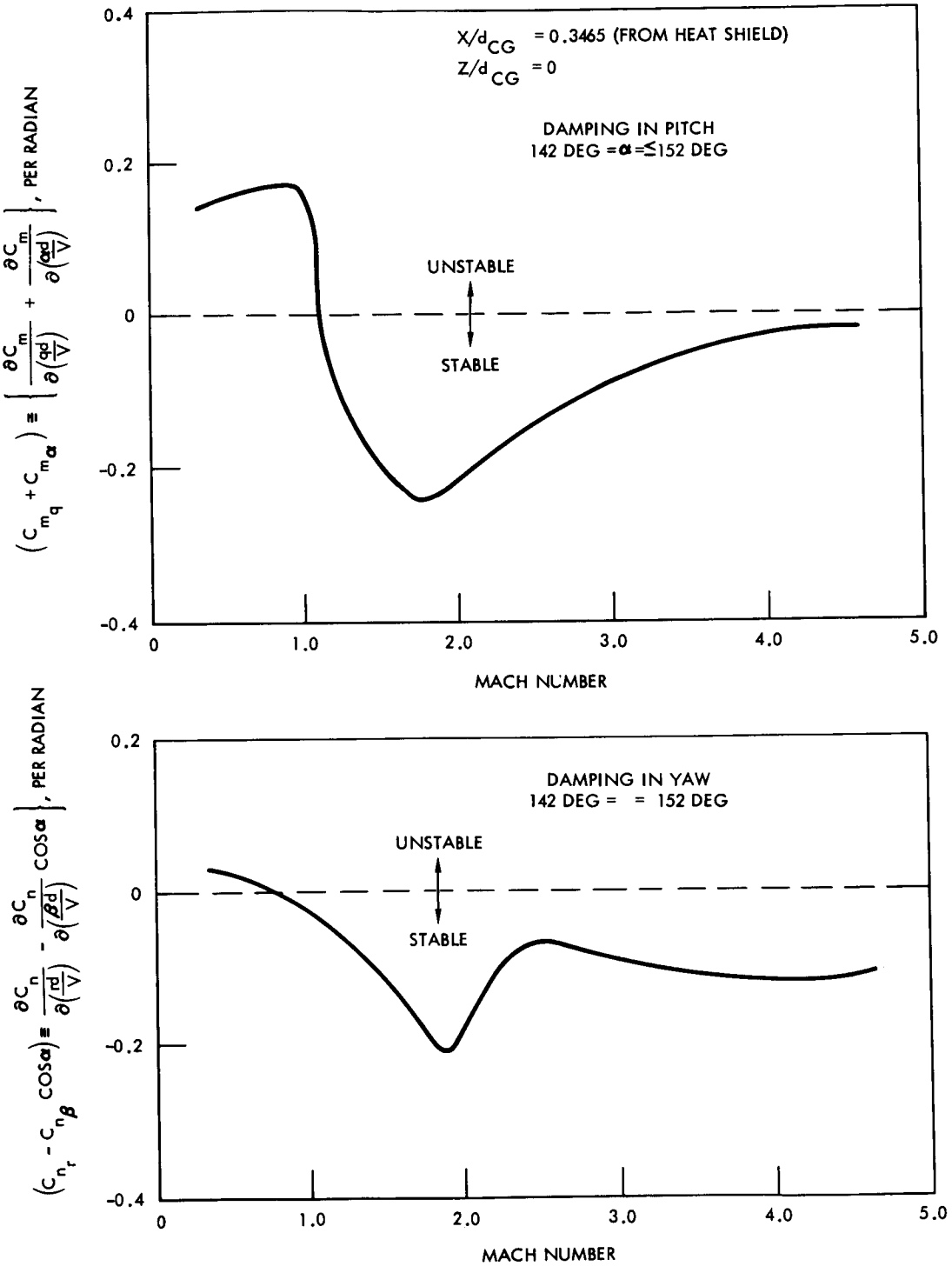


Figure 9. Command Module Damping in Pitch and Yaw

Data obtained in free oscillation tests at the Jet Propulsion Laboratory have been received and are being analyzed. The tests were conducted over the Mach number range from 2.6 to 9.3. In these tests, the axis of rotation of the model was in agreement with the design center of gravity.

Launch Escape Vehicle

The effects of escape rocket operation on the static aerodynamic characteristics of the launch escape vehicle are being considered in terms of two major influences, the aerodynamic interference of the jet plumes and the impingement of the jet on the command module surface. The presence of the plumes has a tendency to obstruct the flow of free-stream air and to "shadow" a portion of the command module area. This interference has a destabilizing effect on the vehicle. If the jet impinges on the surface of the command module, the pressure is increased over the impinged area and a local force is produced. As the angle of attack is increased, the impingement increases on the windward side resulting in forces that have a stabilizing effect. Since the interference and impingement effects tend to oppose each other, there is not a radical difference between jet-on and jet-off characteristics near the trim point.

From data obtained at the Langley Unitary Plan Wind Tunnel (low-speed leg), a comparison was made of launch escape vehicle damping in pitch with and without the stabilizing washer. (Figure 10). The test center of gravity (center of rotation) was not consistent with the true center of gravity of the launch escape vehicle because of physical limitations. The trend of the data, however, should not be greatly affected by the center-of-gravity difference. This trend indicates that the washer substantially reduces damping at low angles of attack. At the higher angles of attack, the test data indicate the washer-on configuration gives better damping characteristics. However, it is considered that an insufficient number of test points were available above 6 degrees angle of attack to make a definite conclusion. Future tests will provide more data at higher angles of attack.

Boost Flight System

Static pressure distributions during boost for the command module, service module, and adapter were obtained from tests of the PSTL-1 launch escape model in the NAA Trisonic wind tunnel. A typical distribution is presented in Figure 11. These data indicate a definite venting problem due to the extremely low pressures in the vicinity of the command module and service module interface. A decision was made to seal the forward portion of the service module and vent in the region of the S-IV flare to prevent negative pressures in the service module during boost.

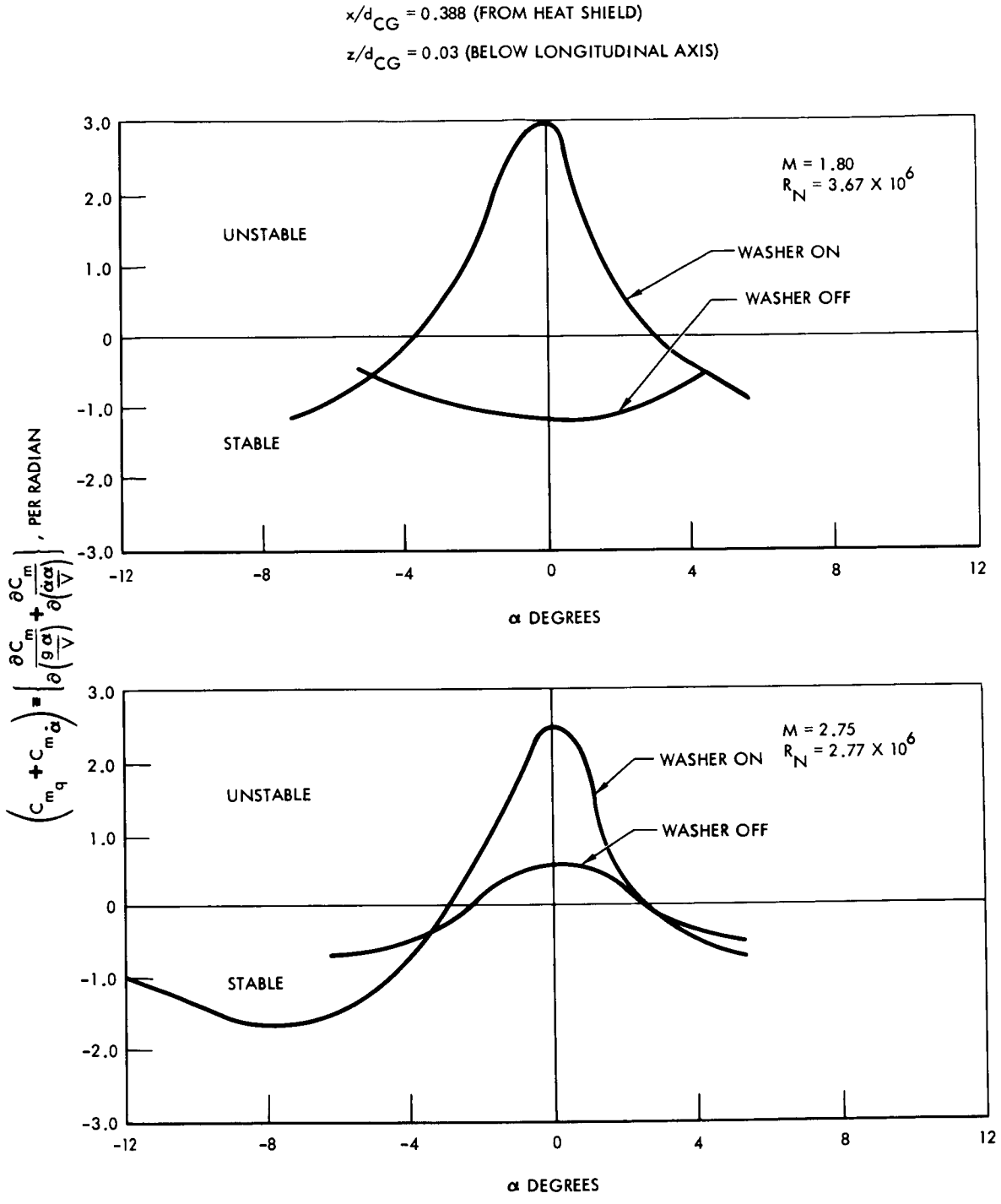


Figure 10. Comparison of Launch Escape Velocity Damping in Pitch With and Without Washer

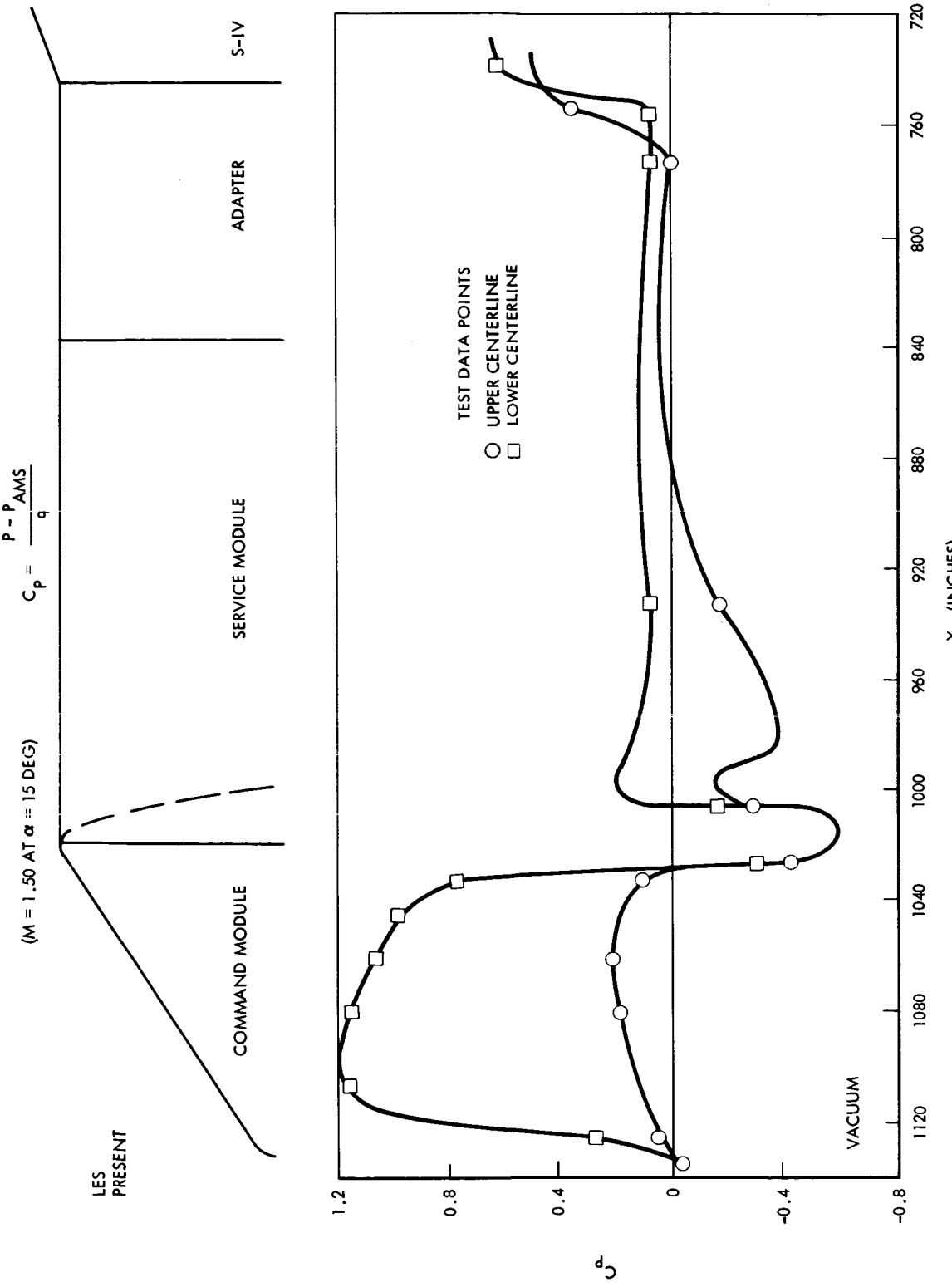


Figure 11. Typical Pressure Distribution for the Command Module, Service Module, and Adapter

Jet Impingement Studies

The boundaries of a jet plume exhausting from a supersonic nozzle in quiescent air increase with the increase in altitude or reduction in the ambient pressure. If the surface supporting the rocket motor extends downstream of the nozzle, jet impingement upon the supporting surface is unavoidable at high altitudes. The loads induced by this impingement could be rather large. It is conceivable that a situation would arise where the induced load would be as large or larger than the engine thrust. This point has been already substantiated in the case of finite free-stream velocity.

To predict the induced load resulting from jet impingement, an empirical method suitable for hand computation has been developed to estimate the centerline pressure distribution on the adjacent surface. Comparison of the results of this method with experimental data for a typical case is presented in Figure 12. By integration of such a distribution over the affected area, the induced force and moment may be easily determined. The method is being programmed for machine computation in conjunction with plume-shape estimates to determine the impingement loads for a number of cases of interest.

FLIGHT DYNAMICS

Service Propulsion System (SPS) Gimbal Actuator Requirements

A preliminary study of the SPS gimbal actuator has been conducted to define system design criteria. Feasibility of a reduction in the requirements for gimbal deflection acceleration and rate was particularly emphasized. For the purposes of this study, the criteria associated with a midcourse velocity correction determine the design condition. Initial results indicate that minimum tolerable gimbal actuator acceleration requirements are considerably lower than originally specified.

Separation

Techniques for separating the command module and service module from the booster have been evaluated for normal and abort modes of operation. It is apparent that the abort criteria are the most stringent from a separation standpoint; somewhat arbitrary criteria have been employed in the design evaluation. Methods considered included using the service module and RCS for separation and ullage, fire-in-the-hole by the SPS with ullage provided by the booster thrust tail-off, booster retrograde rockets, and posigrade rockets attached to the adapter or service module. On the basis of minimum weight and maximum performance capability in the event of abort, the use of posigrade rockets appears to be the optimum system.

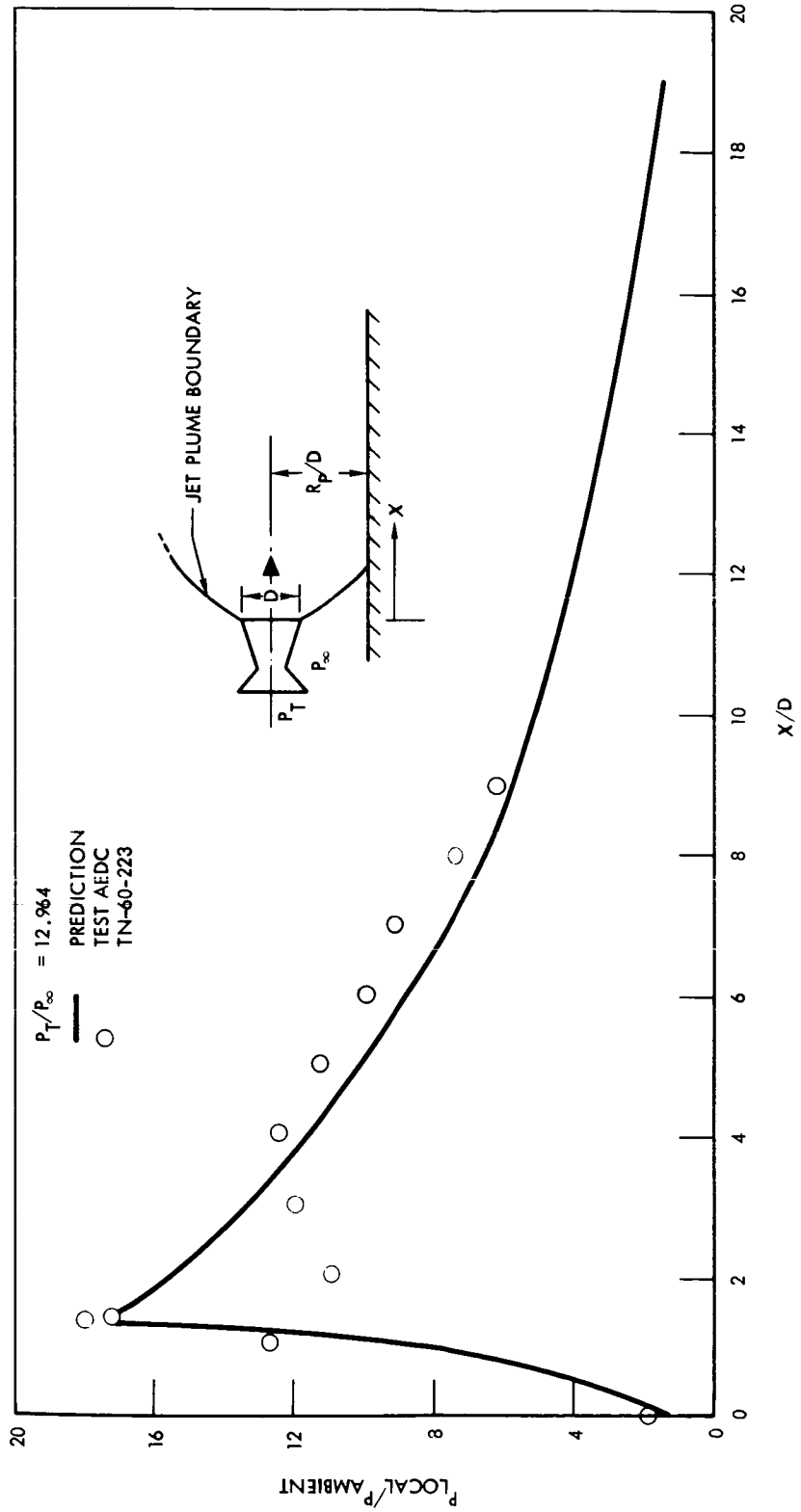


Figure 12. Comparison of Predicted and Experimental Pressure Distribution Along Flat Plate Due to Jet Impingement

## Attitude Orientation Following High-Altitude Abort

Dynamics of the high-altitude LES abort are being investigated. Initial results indicate that damping of the induced body rates of the command module is mandatory and that the RCS is capable of performing this maneuver. Requirements and means of achieving orientation following vehicle damping are presently under study. The relative merits of manual and automatic reorientation are being investigated, and the feasibility of providing reorientation by elimination of the apex-forward aerodynamic trim point is under consideration.

## Service Module RCS Requirements

Preliminary maneuver and orientation requirements for the service module RCS have been established for the lunar landing mission employing lunar orbital rendezvous. It is estimated that 944 pounds of propellant will be required to provide the rotational damping of induced transients, docking capability, and propellant settling of the main tank; to furnish nominal midcourse correction capability; and to perform separation and angular orientation maneuvers. A breakdown of the propellant consumption for the various phases of flight is shown in Table 4. The total propellant includes reserve and redundant propellant for failure mode operation.

## Entry Dynamics

A 6-degree-of-freedom simulation study has been conducted to determine fuel requirements and duty cycles during a manually controlled reentry. Fuel expenditure has been determined for entry ranges varying from 1000 to 4000 nautical miles using both a single and a dual RCS. Results indicate that for all cases a vehicle with a single reaction system controlled by the pilot requires less fuel (Table 5 ).

Further simulation studies are being conducted including updated aerodynamic data, reaction motor thrust characteristics, instrument limitations and dynamics, and center-of-gravity and inertia characteristics. The effect of these factors on vehicle short-period dynamic characteristics during entry is being investigated.

## Launch Escape System

A passive LES has been designed using a kicker rocket with a total impulse of between 1200 and 3000 pounds seconds in the first 0.5 seconds following initiation of abort. The main motor (155,000 pounds of thrust) is aligned 2.8 degrees with respect to the center line resulting in a downrange abort with the astronauts rotating heels-over-head. To ensure satisfactory aerodynamic stability in the presence of somewhat unpredictable

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Table 4. Service Module RCS Propellant Required for the Lunar Landing Mission With the Lunar Excursion Module

| Function Phase Totals | | | | |
|---|---|---|---|---|
| | Trans-lunar (lb) | Lunar (lb) | Trans-earth (lb) | (lb) |
| Arrest tumbling | 4.8 | 3.6 | 7.2 | 15.6 |
| Navigational sighting orientations | 39.0 | 12.1 | 22.5 | 73.6 |
| $\Delta$V Orientations | 151.8 | 11.5 | 23.1 | 186.4 |
| Miscellaneous orientations | 8.0 | 12.8 | 4.0 | 24.8 |
| Docking | 77.0 | 84.0 | 0 | 161.0 |
| Propellant settling maneuvers | 32.5 | 18.8 | 45.0 | 96.3 |
| Midcourse correction (with RCS) | 0 | 0 | 100.0 | 100.0 |
| Pilot rotational maneuvers | 0 | 20.0 | 0 | 20.0 |
| Command module - service module separation | 0 | 0 | 10.0 | 10.0 |
| Attitude hold | 1.3 | 8 | 5.7 | 15.0 |
| Propellant required per phase | 314.4 | 170.8 | 217.5 | 703 |
| Propellant required per cluster | 79 | 54 | 103 | 236 |
| Propellant required per mission | | | | 944 |

Table 5. Tabulation of Reentry Fuel Consumption and Motor On-Time

| $\gamma$ = -6.4 | | | | | | |
|---|---|---|---|---|---|---|
| Range (nautical miles) | Total Fuel | | Total On-Time | | Time of Flight | |
| | Single | Dual | Single | Dual | Single | Dual |
| 2000 | 48.8 | 78.3 | 140 | 112.5 | 508 | 549 |
| 3000 | 68.5 | 172* | 197 | 248 | 859 | 825 |
| 4000 | 65 | 67.3 | 187 | 97.3 | 975 | 1042 |
| $\gamma$ = -7.4 | | | | | | |
| Range (nautical miles) | Total Fuel | | Total On-Time | | Time of Flight | |
| | Single | Dual | Single | Dual | Single | Dual |
| 1000 | 57 | 56.3 | 164 | 81 | 289 | 378 |
| 2000 | 46.5 | 77 | 134 | 111 | 637 | 591 |
| 3000 | 42.5 | 58.0 | 123 | 83.5 | 753 | 788 |
| *Excessive Pilot Control Action | | | | | | |

jet plume effects, a capacity for carrying 1500 pounds of ballast has been built into the LES tower.

Separation of the tower from the command module 16 seconds after escape has been determined as optimum during abort over the entire flight regime. The tower jettison motor (33,000 pounds of thrust, 1.0 second of burning time) is to be aligned 2.5 ±0.5 degrees in pitch and 0. ±0.5 degrees in yaw.

Use of the passive system results in a tumbling condition following abort at altitudes above approximately 125,000 feet (Figure 13). Tumbling rates upon abort may be sufficient to cause a loss of the inertial reference system.

[redacted]

NOTES:
1. KICKER ROCKET: 3400-LB THRUST, 0.50 SECONDS
2. LES MOTOR: 125,000-LB THRUST/NOMINAL ALIGNMENT - 2.8 DEGREES
3. WEIGHT DATA: 8125 LB COMMAND MODULE, 8607 LB LES INCLUDING 375 LB BALLAST
4. AERODYNAMIC DATA: TWICE THE PREDICTED JET-PLUME EFFECT ASSUMED, BASED ON "SHADOW EFFECT" ONLY.

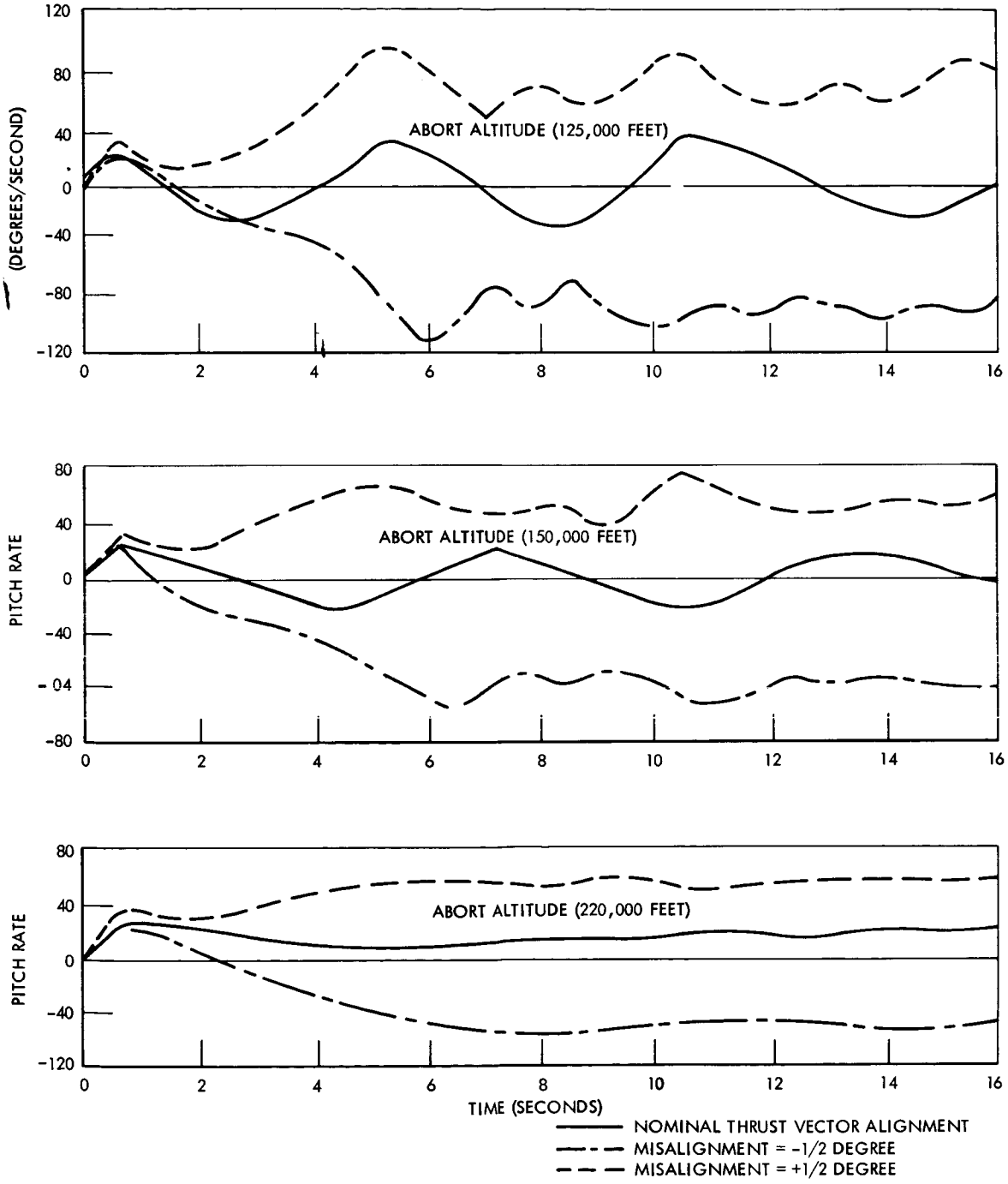


Figure 13. Launch Escape Pitch Rate Histories for Aborts at High Altitude



[redacted]

Recovery System

A comprehensive plan encompassing wind tunnel and drop testing of the recovery system has been proposed and is being issued. The proposed program is designed to provide sufficient information to enable a thorough investigation of the recovery system dynamics over the entire flight regime and to provide system performance for certain specified flight conditions. Wind tunnel testing, principally of the drogue, will be conducted at several facilities and will culminate in free-flight tests at Langley. Special parachute test vehicles and boilerplates will be drop tested at the El Centro facility.

An analytical investigation of drogue parachute/command module stability characteristics is in progress. This study will augment the wind tunnel test program and consists of mathematical model formulation for computer simulation and application of theoretical methods. Initial effort is directed toward determining the effect of attachment geometry, drogue size, line length, and parachute lateral motion on command module stability.

Data is being reduced for all parachute drops and is being correlated with empirical performance equations based upon dimensional analysis and exact equations where possible. This effort is part of a program to develop equations for prediction of recovery system performance, such as inflation and load function, stability characteristics, and rate of descent.

## PERFORMANCE AND TRAJECTORIES

Boost Phase

Revised nominal trajectories for the C-1 and the C-1 with the service module have been determined for the launch vehicle stage weights listed in MSFC report M-AERO-PT-11-62 dated 26 April 1962. The 100-nautical-mile maximum earth orbital payloads obtained (based on a 6600-pound LES tower) were 18,695 pounds for the two-stage C-1 and 22,414 pounds using the service module for orbit injection. These payloads include only the command module and service module.

Loads trajectories have been determined for the Saturn-Apollo C-1, the C-1 with the service module, and the C-1B. Criteria used to establish these trajectories are as follows:

1. Launch vehicle weights obtained from NASA on 8 August 1962

2. Most severe and optimum combinations of 3-sigma deviations in thrust, stage weight, and exhaust velocity

3. Wind shear which will not be exceeded 99 percent of the time (MSFC report MTP-AERO-61-48)

The first two criteria are combined to establish trajectory velocity and altitude dispersions during first-stage boost. Wind shear is applied to these trajectories to obtain the most severe $q_o$ wind loads (drift-minimum method). In addition, attitude displacement ($a_o$) and angle of attack ($b_o$) gains are varied by 10 percent with and without cross-flow effects to determine their effect on $q\alpha$. Table 6 presents the maximum $q_o$ values obtained and the assumed conditions for maximum q trajectories.

Table 6. Maximum $q_o$ Values (Degree-Pounds Per Square Foot)

| Vehicle Assumptions | | | Vehicle Configuration | | |
|---|---|---|---|---|---|
| $a_o$ | $b_o$ | Cross Flow | C-1 | C-1 Plus C/M | C-1B |
| 1.0 | 1.0 | None | 5364 | 5307 | 5533 |
| 1.1 | 0.9 | None | 5822 | 5747 | 5933 |
| 1.0 | 1.0 | Yes | 5015 | ---- | 5137 |
| 0.9 | 1.1 | None | 4918 | 4876 | 5130 |
| 1.1 | 0.9 | Yes | 5443 | ---- | 5516 |
| 0.9 | 1.1 | Yes | 4605 | ---- | 4763 |

The maximum $q\alpha$ obtained is 5933 degree-pounds per square foot and results from the worst combination of control gains with no cross flow on the C-1B launch vehicle.

A typical trajectory established for the Little Joe II maximum q abort test simulates the C-1 flight path angle ($\gamma$) in addition to the velocity and altitude conditions. A lift-off weight of 97,000 pounds, including ballast, at a launch angle of 84.85 degrees under no-wind conditions will result in the desired test conditions 41.3 seconds after lift-off. The range at abort initiation is 2.7 nautical miles. The Little Joe II apogee is 52,000 feet, and its range to impact is 11.4 nautical miles. Little Joe II-Apollo boost performance envelopes for various motor configurations and payload weights have been computed for high altitude and very high altitude abort tests. No specific trajectories have been selected for these tests.

## Service Module Propellant Tank Size

The optimum size for design of the service module propellant tank was determined by considering launch vehicle payload, lunar excursion

module weight, performance $\Delta V$ margin, and command module with service module fixed weight trends. The objectives were a maximum lunar excursion module weight and/or $\Delta V$ margin for possible increased payload weight growths, a "minimum" mission capability for possible reduced payload trends, and a tank capacity that would not exceed the present engine reliability limit.

The booster payload was considered uncertain by ±5 percent from the computed NASA value (92, 600 pounds) for these objectives. The minimum mission was considered for a 25, 000-pound lunar excursion module and a 16, 000-pound command module plus service module fixed weight operating with a 10 percent $\Delta V$ performance margin.

The service module tank capacity selected for design to meet the criteria is 45, 000 pounds. The particular weight and performance capabilities for this design point are presented in Table 7.

Table 7. Weight and Performance Capabilities

| Injected Weight (1000 lb) | Propellant Loading (1000 lb) | Lunar Excursion Module Weight (1000 lb) | Fixed Weight (1000 lb) | Margin % |
|---|---|---|---|---|
| 90.0 | 41.5 | 25.0 | 16 | 14.0 |
| 90.0 | 40.5 | 26.0 | 16 | 10.0 |
| 90.0 | 40.5 | 25.0 | 17 | 10.0 |
| 90.0 | 42.5 | 25.0 | 15 | 19.5 |
| 93.5 | 45.0 | 25.0 | 16 | 21.5 |
| 98.0 | 45.0 | 25.0 | 20 | 10.0 |
| 106.0 | 45.0 | 37.2 | 16 | 10.0 |
| 87.5 | 39.0 | 25.0 | 16 | 10.0 |

## Characteristic Velocity Requirements

NASA-recommended $\Delta V$'s were evaluated using NASA gound rules for the lunar landing mission employing lunar orbital rendezvous. The NASA $\Delta V$ for the lunar excursion module pickup maneuver in the abort mode was found to be low; however, the use of a more efficient maneuver into the equal-period orbit allowed the lunar excursion module pickup with $\Delta V$ to spare. The lunar orbit and transearth injection $\Delta V$ requirements were computed as a function of time of the month for various months and years with the assumed NASA landing site at selenographic coordinates

2.5° north, 36.5° east. The maximum ΔV requirements were found to occur in mid-1973 when almost all of the 7-percent safety margin on transearth ΔV was required to perform the mission with a 3-percent control allowance. The NASA ΔV's were found to allow the use of two earth launch windows rather than the stated single window capability.

Lunar Landing Site Studies

The lunar surface area that can be reached any day of January 1967 was determined using the NASA ΔV capability without a safety margin. It was found that two areas exist that are accessible at all times during the month, one on the trailing visible quarter and the other on the leading non-visible quarter. Each area contains approximately two percent of the total lunar surface. In addition to the 100 percent of the month coverage, the total area that can be reached during the month was determined. This area is approximately a broad band bounded by the north and south 21-degree selenographic latitudes and contains 36 percent of the total lunar surface.

Guidance and Performance Interactions

Parametric studies of the influence of outbound and return trajectory inclination and preinjection coast arcs from 180 to 720 degrees on midcourse and lunar orbit maneuver requirements were made for 10 translunar (half circumlunar) trajectories. Since circumlunar trajectories lie close to the lunar equatorial plane, correction of time-of-arrival errors during the midcourse phase is more expensive than removal of the time dispersion after injection into a lunar orbit. Therefore, only corrections of out-of-plane position and perifocal radius were considered in detail.

For a base point measurement rate of one sample per hour and an individual measurement accuracy of 10 arc seconds, the total rms velocity needed to make the required maneuvers and remove the residual control errors after arrival was 44, 27, and 24 feet per second for one, two, and three midcourse corrections respectively. Variations in sampling rate and metering accuracy about the base point were considered. The results were based on the NASA estimates of the errors for the ST-124 platform because the standard Saturn platform without preinjection alignment requires less maneuver potential than an ST-124 boost followed by an injection using the alignable Apollo inertial measuring unit.

Entry Guidance Concept

An atmospheric entry terminal steering concept is being developed to guide the Apollo vehicle to a preselected site having both longitudinal and lateral range requirements. The steering technique is based on

closed-form range prediction solutions. The path increments that make up the range prediction solutions are a constant path angle phase, a ballistic phase, and a subcircular glide phase. Periodically during the entry, a range prediction is made by summing the appropriate phases. The predicted range is compared with the remaining great circle range to go, and a suitable bank angle that will null out the predicted range error is commanded. Lateral range requirements are fulfilled by keeping the vehicle within heading limits that are a function of the range to go and the predicted subcircular range.

## Heat Shield Design Trajectories

Revised trajectories for use in the design of the service module heat shield have been defined and supplied to Avco. These trajectories include boost, LES abort, and atmospheric entry from orbital and escape speeds. The major differences between these and the previous design trajectories are the inclusion of LES aborts and a change in the hypersonic drag parameter, $W/C_DA$, from 50 to 75 psf. The latter value corresponds to a 9500-pound command module weight. The command module lift-to-drag ratio was 0.5 as previously used.

The maximum total heating load trajectory corresponds to an escape speed entry along the overshoot boundary and 5000-nautical mile range. This trajectory results in approximately a 38-percent increase in heating load over the previous design case. The flight path control mode used in the supercircular speed region would result in a near maximum heating load.

Table 8 presents data for the revised supercircular trajectories for initial conditions of $V_{EN}$ = 36,200 fps and $h_{EN}$ = 400,000 feet.

## Command Module Center-of-Gravity Locations

The lift-to-drag ratio determines much of the vehicle performance capability in that the attainable ratio defines the entry corridors, the attainable longitudinal and lateral ranges, the maximum deceleration, and the resulting heating flux and loads. The required lift-to-drag ratio must provide performance capability compatible with mission success and crew safety requirements.

To provide design requirements for the command module prior to completion of mission performance and crew safety analyses, the design objective of the lift-to-drag ratio has been set at 0.50. The following lift-to-drag requirements have been determined for the indicated phases of flight.

| | |
|---|---|
| Boost abort (load limit 15 g's) | 0.35 |
| Earth orbital entries | 0.00 |
| Atmospheric flight envelopes (5000-nautical mile controllable range) | 0.44 |
| Terminal control capability (200 nautical mile subcircular range correction) | 0.38 |

Table 8. Supercircular Trajectories

| Trajectory | EN (Deg) | $G_{Max}$ | Maximum Heating Rate (Btu/ft$^2$) | Maximum Heating Load (Btu/ft$^2$) | Range (Nautical Miles) |
|---|---|---|---|---|---|
| Maximum Heating Load Overshoot Boundary | -5.5 | 2.14 | 588.4 (568.5) | 199,202 (142,191) | 5467 |
| Maximum Heating Load 10 g Undershoot Boundary | -7.72 | 9.88 | 1176 (1556) | 118,690 (96,836) | 5443 |
| Minimum Heating Time (10 g Entry) | -7.72 | 9.88 | 1176 (1556) | 69,620 (65,720) | 708 |
| Minimum Heating Time (Structural Limit, 20 g | -10.0 | 20.01 | 1561 (1561) | 56,076 (59,911) | 496 |

Note: Heating rates and loads shown without parenthesis are based on a radius of 7.7 inches. Heating rates and loads in parenthesis are based on 18.2 inches for stagnation convective heating and 54.2 inches stagnative radiation heating.

## AEROTHERMODYNAMICS

### Aeroheating Analysis

Applicable methods and techniques of predicting heat transfer rates for the Apollo spacecraft were reviewed and evaluated. Knowledge was obtained through an analysis and correlation of the accumulated wind tunnel data. These data were obtained from the JPL and AEDC B and C hypersonic tunnels, NAA shock tunnel, and Avco shock tube facilities.

Some results of these tests (principally of tests conducted at JPL) are presented in this section. Efforts were concentrated on the entry vehicle at 0 and 33 degrees angles of attack. During the next report period, correlation of data will be expanded to include launch configuration, and additional angles of attack of the entry capsule.

Figure 14 shows the stagnation point on the JPL command module model as a function of angle of attack and Mach number. Between 0 and 50 degrees angle of attack, the actual stagnation point shifts toward the central axis and away from the "geometric stagnation point."

At 0 degrees angle of attack, the stagnation point heat transfer rate on the command module is predicted to exceed the value on a hemisphere of the same radius of curvature because of the cut-sphere effect. Test results verify this prediction and indicate the magnitude of the effect as illustrated in Figure 15. This figure shows the ratio of the stagnation point heating rate measured on the Apollo to that calculated on a hemisphere of an equal radius of curvature at 0 degrees angle of attack as a function of the hypersonic parameter $M^3/(Re_D)^{1/2}$. The ratio is shown to be nearly constant for the range of test data shown.

The method used to predict the laminar heat transfer distribution on the entry face of the JPL model at 33 degrees angle of attack was that of Lees[1], based on local similarity. Although the method applies to planar and axisymmetric shapes, it was found that this method could be used to predict test data with a fair amount of accuracy when simplified assumptions to the local Apollo geometry were employed. A comparision of the theory and data is shown for nominal Mach numbers 6, 7, and 9 in Figure 16.

A comparison of the laminar heat transfer distribution as measured on the Apollo face for $\alpha$ = 33 degrees at various facilities (JPL, AEDC C and Avco) is shown in Figure 17. Although some discrepancies are seen among these data, the general trends are in agreement.

[1] Lees, L., "Laminar Heat Transfer over Blunt-nosed Bodies at Hypersonic Flight Speeds," Jet Propulsion, Vol. 26, 4 November 1956.

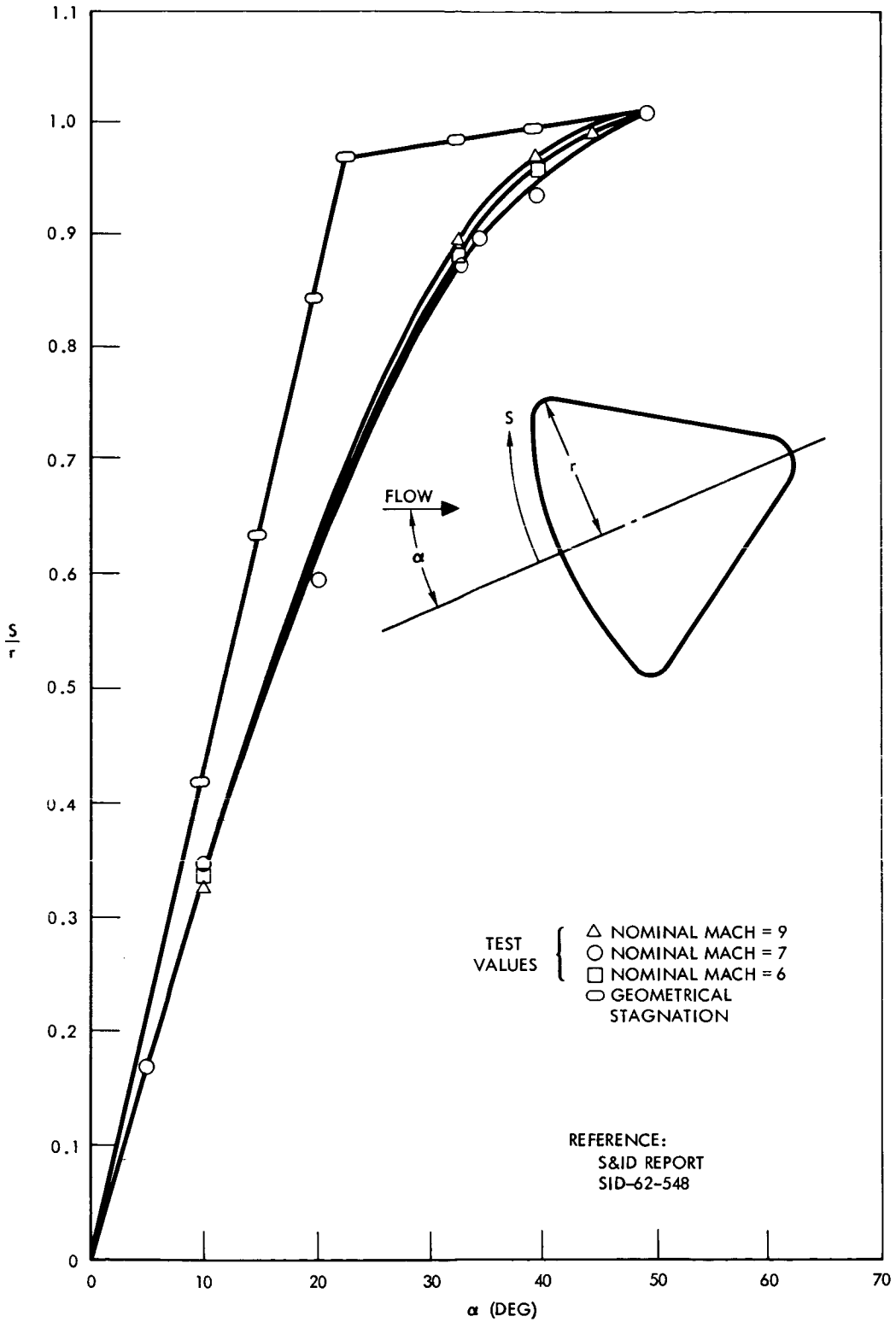


Figure 14. Stagnation Position With Angle of Attack and Mach Number

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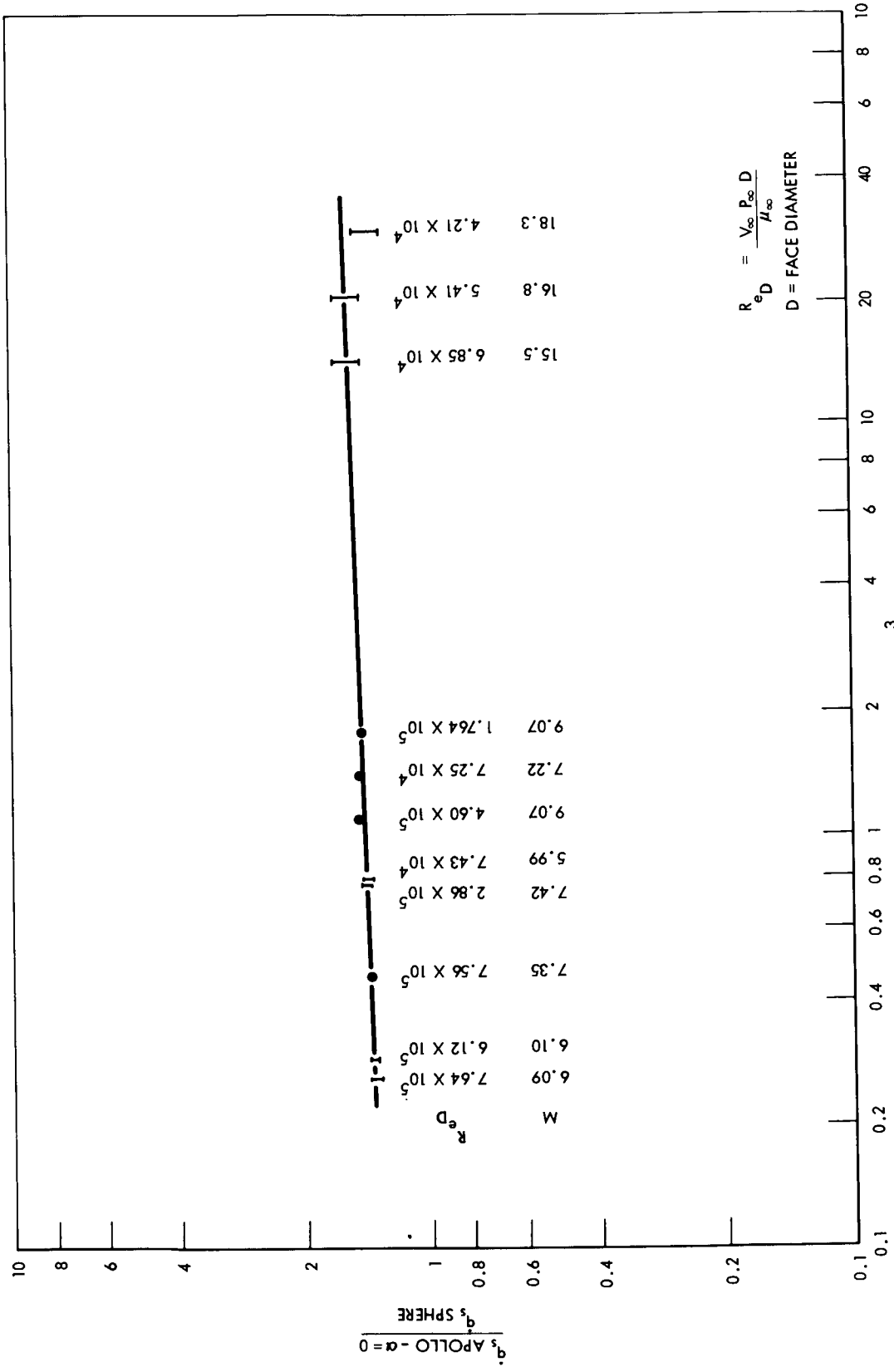


Figure 15. Correlation of $\frac{\text{qs Apollo}}{\text{qs Sphere}}$ With $\frac{M^3}{(Re_D)^{1/2}}$

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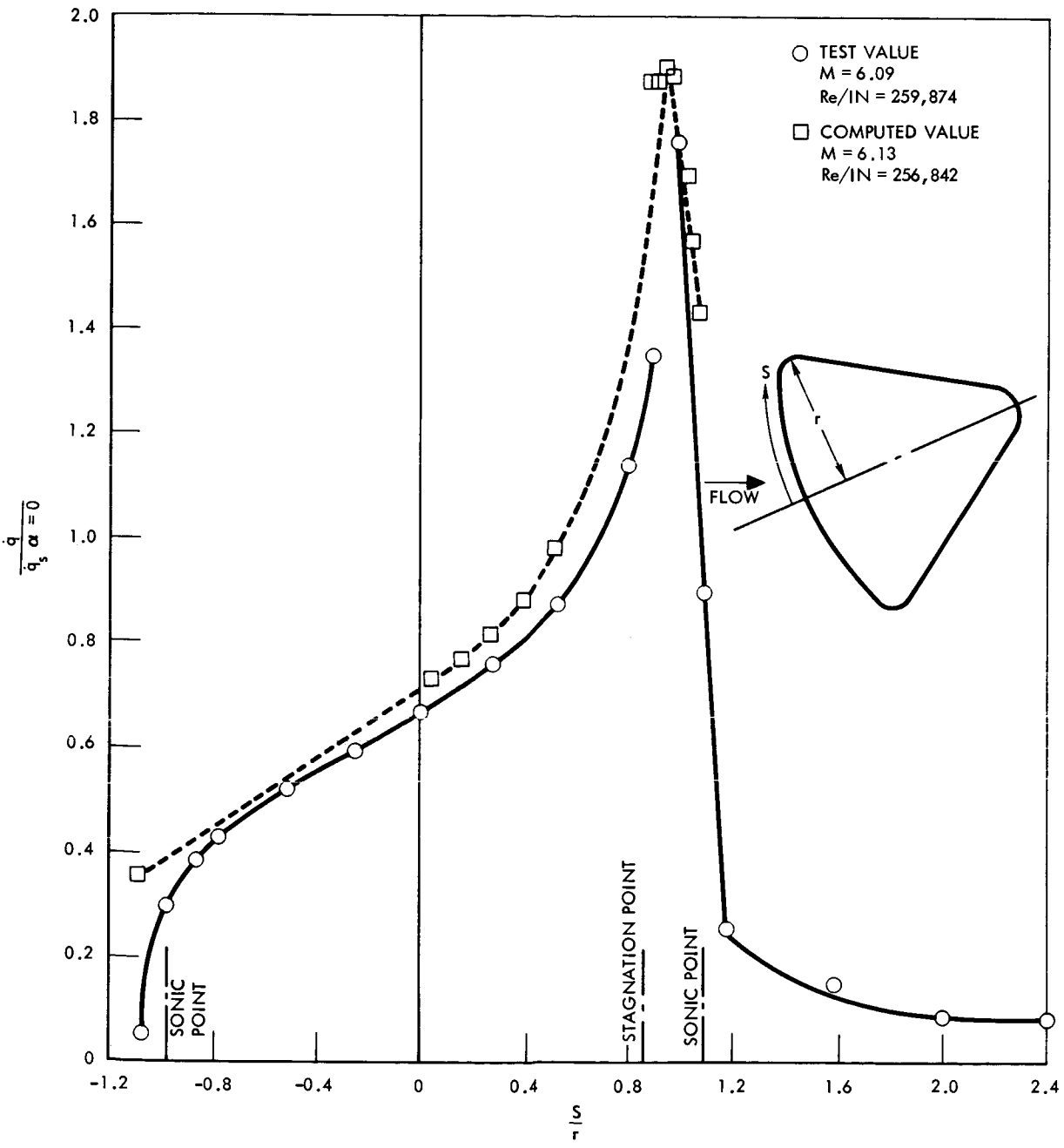


Figure 16. Heat Flux Distribution— $\alpha$ = 33 Degrees (Sheet 1 of 3)

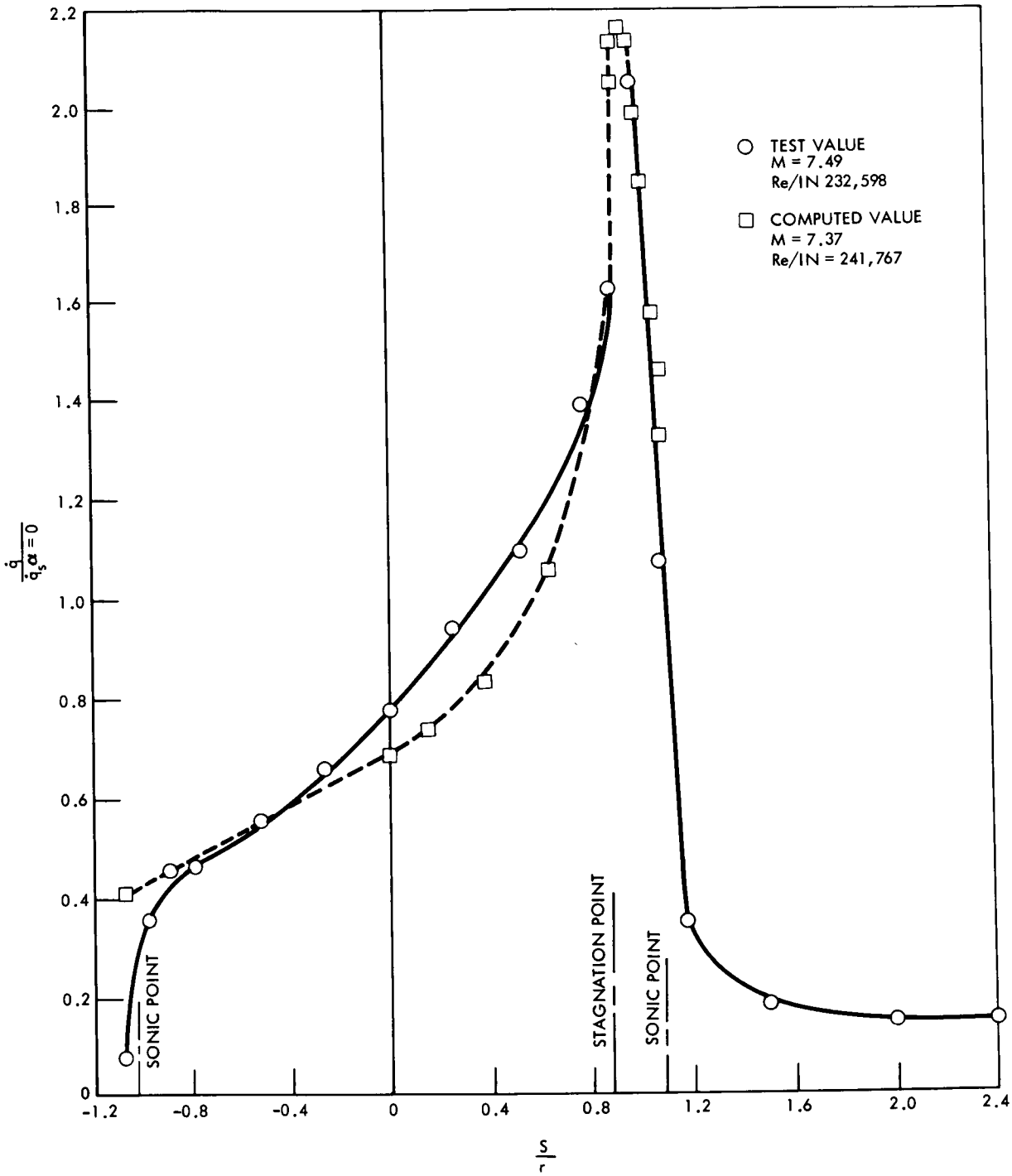


Figure 16. Heat Flux Distribution— $\alpha$ = 33 Degrees (Sheet 2 of 3)

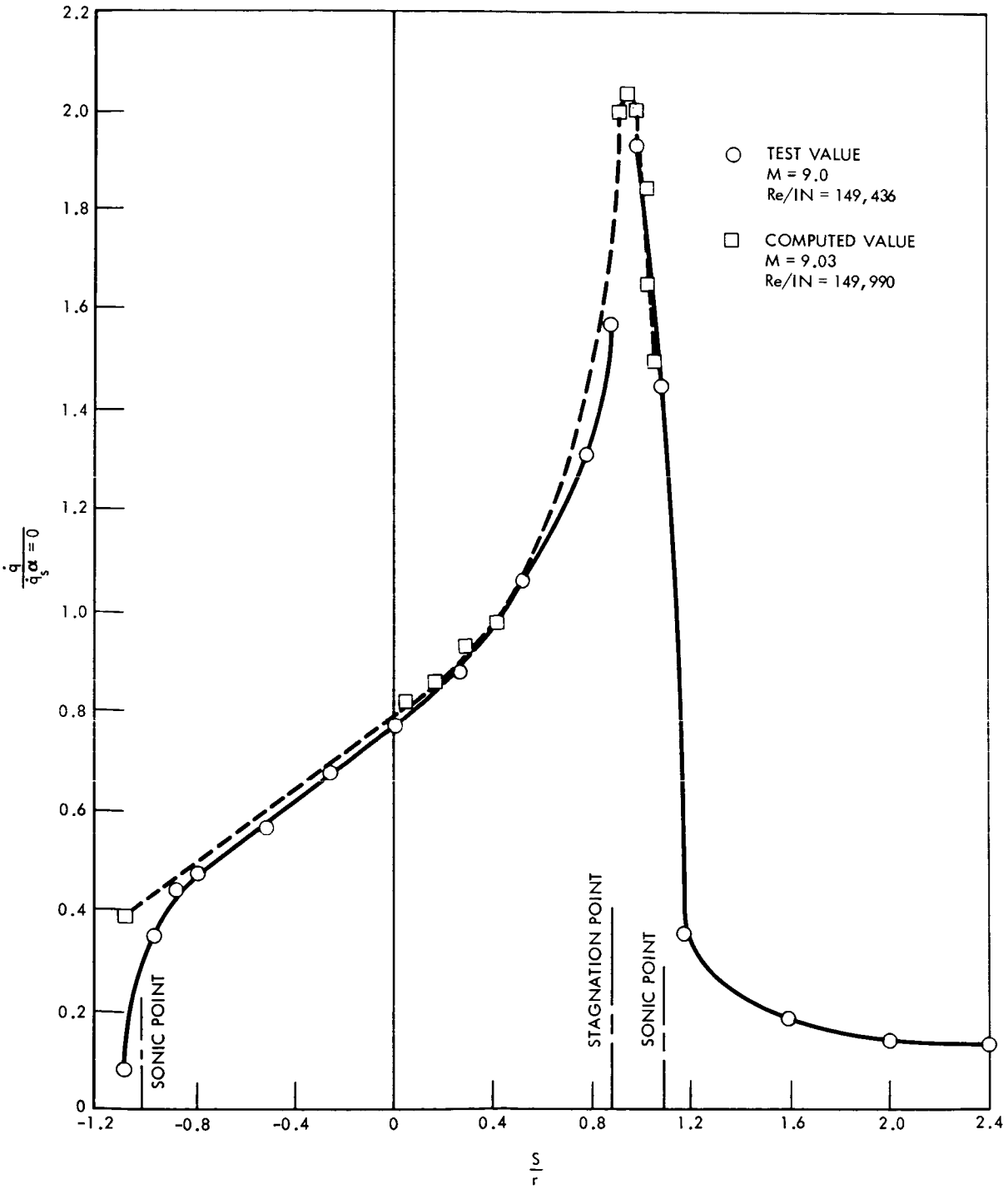


Figure 16. Heat Flux Distribution— $\alpha$ = 33 Degrees (Sheet 3 of 3)

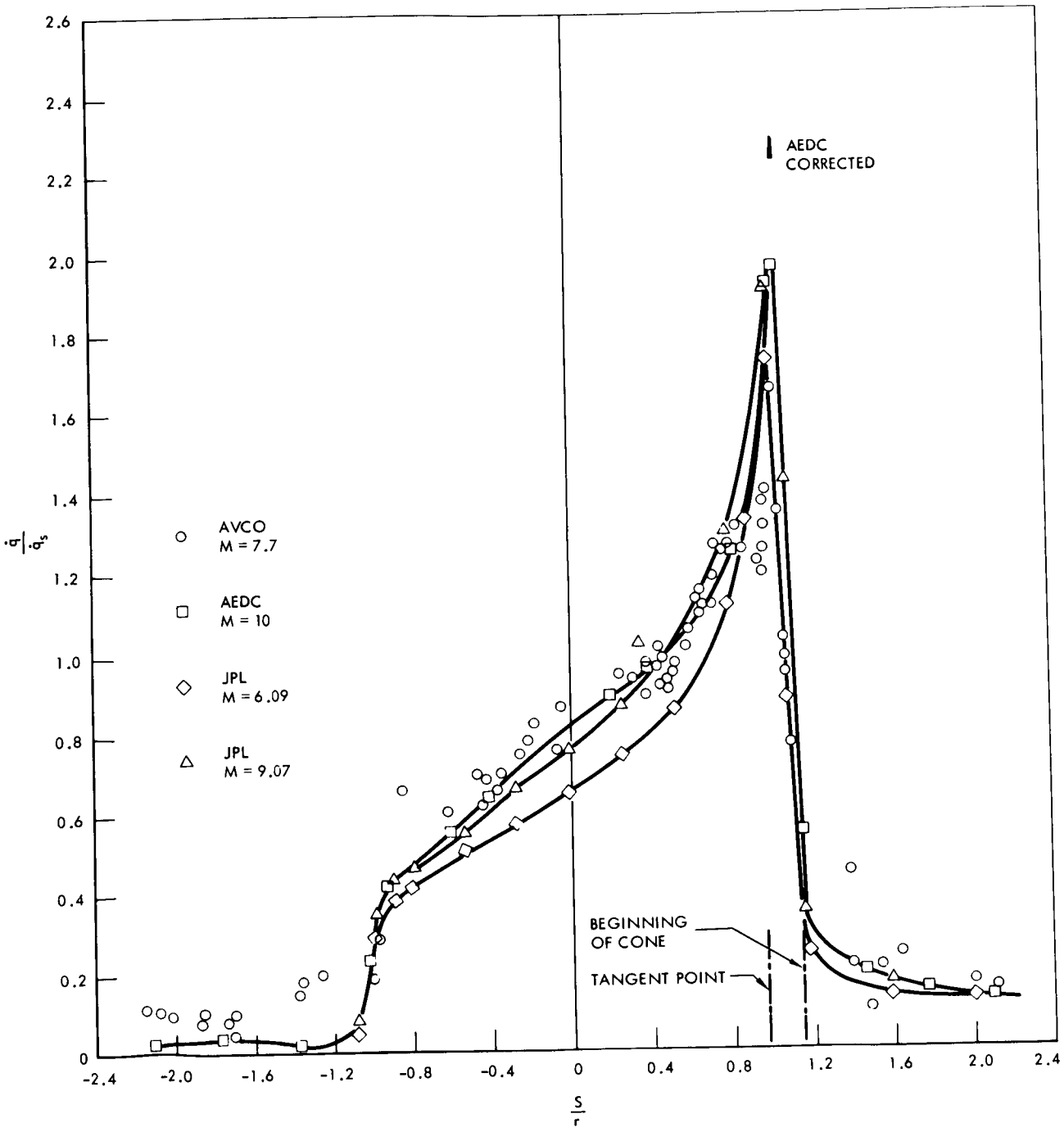


Figure 17. JPL, AEDC, and AVCO Data Comparison

The heating rate data for nine additional surface locations on the command module indicate that a lighter heat shield design is feasible. To accommodate these additional points, and to provide a more versatile computation of heating rate estimates, a new computing program was written. The subroutine construction of this program gives it greater computing capacity and added flexibility.

Another computer program was developed to predict heating caused by rocket exhaust plume impingement. Radiative heat transfer is also calculated by this program using the Stefan-Boltzman equation and the pertinent gas properties.

## Wind Tunnel Test Program

The first series of aerodynamic heating tests in the AEDC B and C tunnels was completed. Thin-skin 0.045-scale models were used. Table 9 is a summary of the test conditions. Correlation of the data has begun and will continue during the next report period.

Table 9. Summary of AEDC Test Conditions

| Re/Ft | $Pt_1$ (psia) | $Tt_1$ (°R) |
|---|---|---|
| TUNNEL B (MACH 8.0) | | |
| 450,000 | 102 | 1335 |
| 685,000 | 154 | 1327 |
| 1,000,000 | 227 | 1328 |
| 1,600,000 | 373 | 1348 |
| 1,915,000 | 465 | 1360 |
| 2,400,000 | 560 | 1338 |
| 3,480,000 | 850 | 1365 |
| TUNNEL C (MACH 10.0) | | |
| 330,000 | 212 | 1663 |
| 400,000 | 265 | 1695 |
| 620,000 | 454 | 1773 |
| 990,000 | 755 | 1810 |
| 1,600,000 | 1280 | 1862 |
| 1,960,000 | 1600 | 1880 |
| 2,000,000 | 1630 | 1860 |

The entry heating tests of the command module RCS are in progress. The first series of runs has been completed, and the data are presently being analyzed.

## ATMOSPHERIC HEAT TRANSFER

### Launch Escape System

An investigation was made to determine the heating of the LES flow separator during boost. Results indicate that the unprotected separator may heat to 1580 F during this time. The desired maximum component temperature is 600 F. Results of this study revealed that 0.2 inches of laminated fiberglass insulation would offer sufficient thermal protection.

### Command Module

A proposal for a heat shield qualification test program was completed. The test program includes thermal, structural, composite thermal-structural, and flight testing. The proposed program recommends the construction of a "practice" heat shield by Avco, a Mercury earth orbital entry flight test using Apollo heat shield materials, a flight test of a scale model Apollo at lunar entry velocities, and initiation of a "back-up" heat shield program.

Thirty-five ablation samples were tested in an arc jet, and results indicate that it is feasible to permit holes to penetrate the ablative heat shield on the Apollo command module. Although the tests were qualitative rather than quantitative, the following preliminary conclusions may be drawn:

1. Maximum permissible hole diameter is 1/4 inch
2. Minimum permissible hole spacing is three times the hole diameter (center to center)
3. All holes must be dead-ended
4. The required ablative material thickness must be increased by 25 percent

Additional tests are planned to verify or modify these conclusions.

Results of the protuberance testing showed that it is feasible to permit the 1/4-inch tension ties (between the command and service modules) to remain in the heat shield during reentry. However, a weight penalty in addition required ablative material will be incurred.

Further arc jet tests are planned in support of the design effort.

Service Module

Based on a maximum allowable temperature of 375 F, calculations have shown that any face thickness greater than 0.019 inches may be used with a core density of 2 pounds per cubic foot during boost heating of the honeycomb adapter at the base of the service module. Any face thickness greater than 0.0165 inches may be used with a core density of 3 pounds per cubic foot.

Table 10 shows the maximum expected adapter temperatures for various thicknesses ranging from 0.015 to 0.025 inches.

Table 10. Adapter Maximum Inner and Outer Face Temperatures for Various Face Thicknesses and Core Densities

| | Core Density | | | |
|---|---|---|---|---|
| | 2 lb/ft$^3$ | | 3 lb/ft$^3$ | |
| Face Thickness | $T_1$ (F) | $T_2$ (F) | $T_1$ (F) | $T_2$ (F) |
| 0.015 | 422 | 395 | 388 | 351 |
| 0.016 | 408 | 381 | 378 | 340 |
| 0.017 | 396 | 368 | 369 | 330 |
| 0.018 | 385 | 357 | 361 | 321 |
| 0.019 | 375 | 346 | 353 | 313 |
| 0.020 | 366 | 336 | 346 | 305 |
| 0.021 | 358 | 327 | 339 | 297 |
| 0.022 | 350 | 319 | 330 | 291 |
| 0.023 | 342 | 311 | 327 | 284 |
| 0.024 | 335 | 304 | 321 | 278 |
| 0.025 | 329 | 397 | 316 | 272 |

$T_1$ = Temperature of outer panel face
$T_2$ = Temperature of inner panel face

SPACE HEAT TRANSFER

Command Module

An analysis was made to determine the minimum expected surface temperature of the command module for space missions that include the lunar excursion module. This evaluation was based on the assumptions that the insulation will dominate the heat transfer between the inner and

outer structures, the insulation thickness is 0.111 feet, and the inner cabin will be maintained at a constant temperature of 75 F. Results of the analysis are shown in Figures 18, 19, and 20. Figure 18 gives surface temperatures as a function of thermal conductivity of the insulation material (command module shielded from solar radiation by the lunar excursion module). Figure 19 shows surface temperature variation with angle of incidence of solar energy for an ablative material having an emissivity and absorptivity of 1.0. Figure 20 shows surface temperature variation with angle of incidence of solar energy for a surface coated with white paint (absorptivity is 0.35 and emissivity is 0.75).

Figure 19 shows that a minimum surface temperature of -287 F can be expected for an insulation thermal conductivity of $10^{-7}$ Btu/sec-ft$^2$-°F. These results indicate that a vehicle orientation in which solar radiation would be periodically incident on the command module surfaces may be required to increase surface temperatures to an acceptable level.

A thermal analysis was made of the command module aft equipment compartment and heat shield for all space mission phases. This evaluation was based on the service module environmental temperatures obtained from a study of individual propellant tank thermal protection requirements. Results show that the minimum temperature of the stainless-steel honeycomb structure reached -140 F during space flight. Figure 21 shows the temperature history of the honeycomb structure (element No. 15) during the translunar, lunar-orbit, and transearth mission phases. The condition of the interiors of the insulated service module shell is presently being investigated.

## Service Module

A parametric investigation to determine propellant thermal protection requirements during space operations when a high-vacuum insulation is placed on the inside of the service module shell and on the radial shear panels was completed. This analysis was based on a two-dimensional model as shown in Figure 22.

For analysis purposes, the Apollo mission was divided into translunar, lunar-orbit, and transearth phases. It was assumed that the service module was shielded from the sun by the command module during the translunar and transearth mission phases.

Initial results indicate that approximately 0.1 inch of insulation will be required to prevent freezing of the propellant. The effect of thermal conductivity on the required insulation thickness is shown in Figure 23. Much thicker insulation will be required if an insulation with a thermal conductivity of $3 \times 10^{-4}$ Btu/hr-ft$^2$-°F is used.

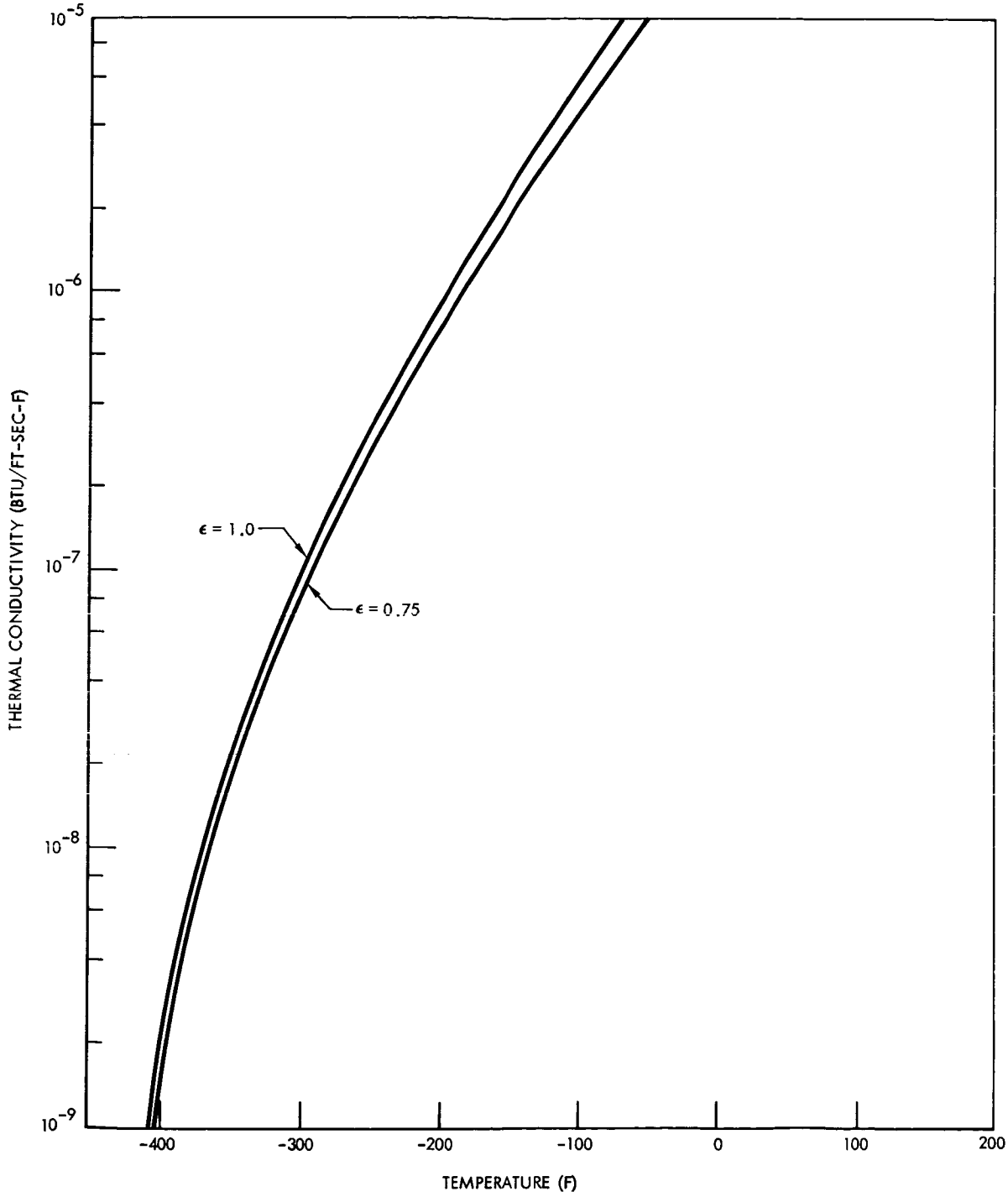


Figure 18. Surface Temperature Variation With Thermal Conductivity

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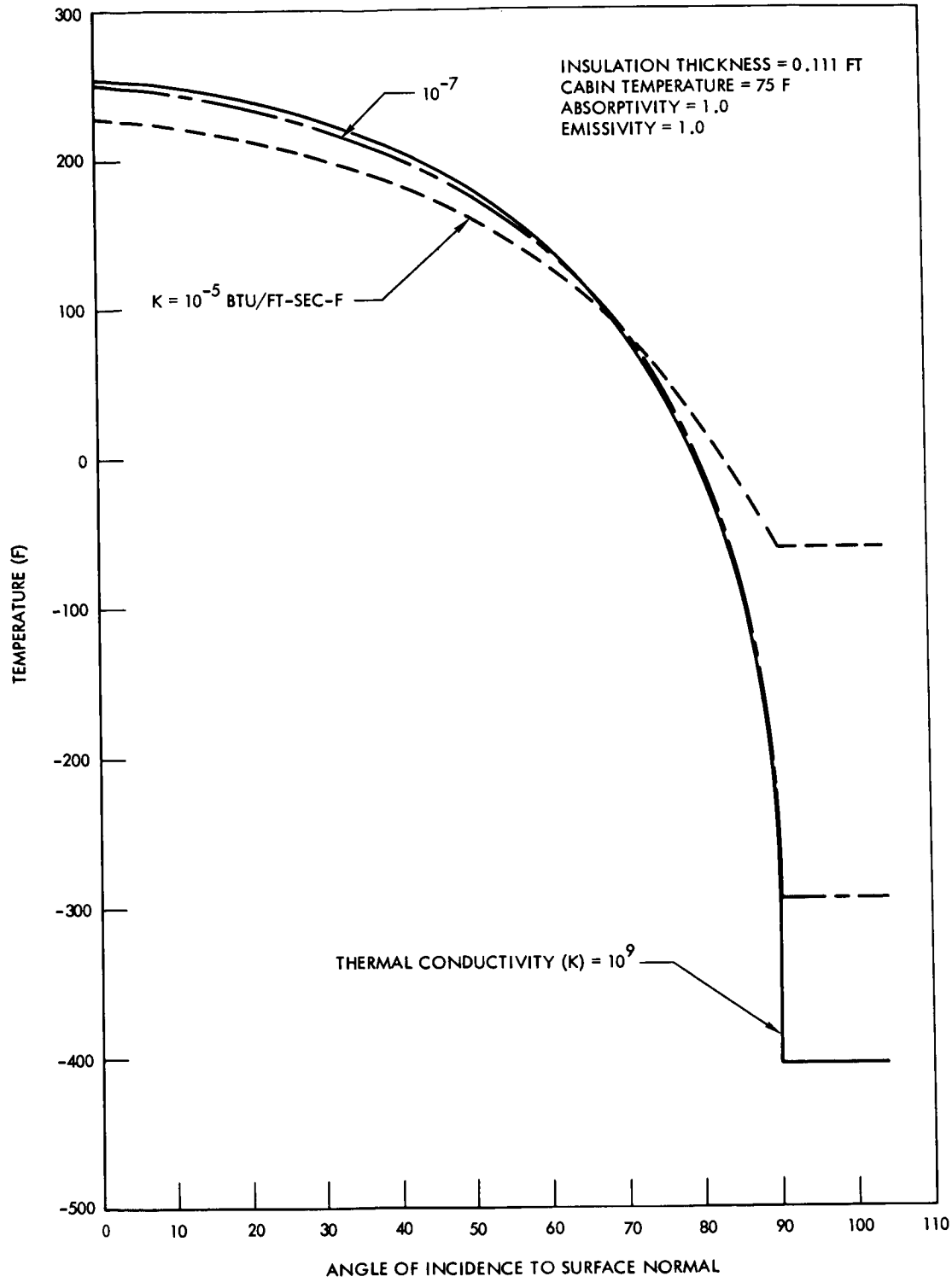


Figure 19. Surface Temperature Variation With Angle of Incidence of Solar Energy (Ablator)

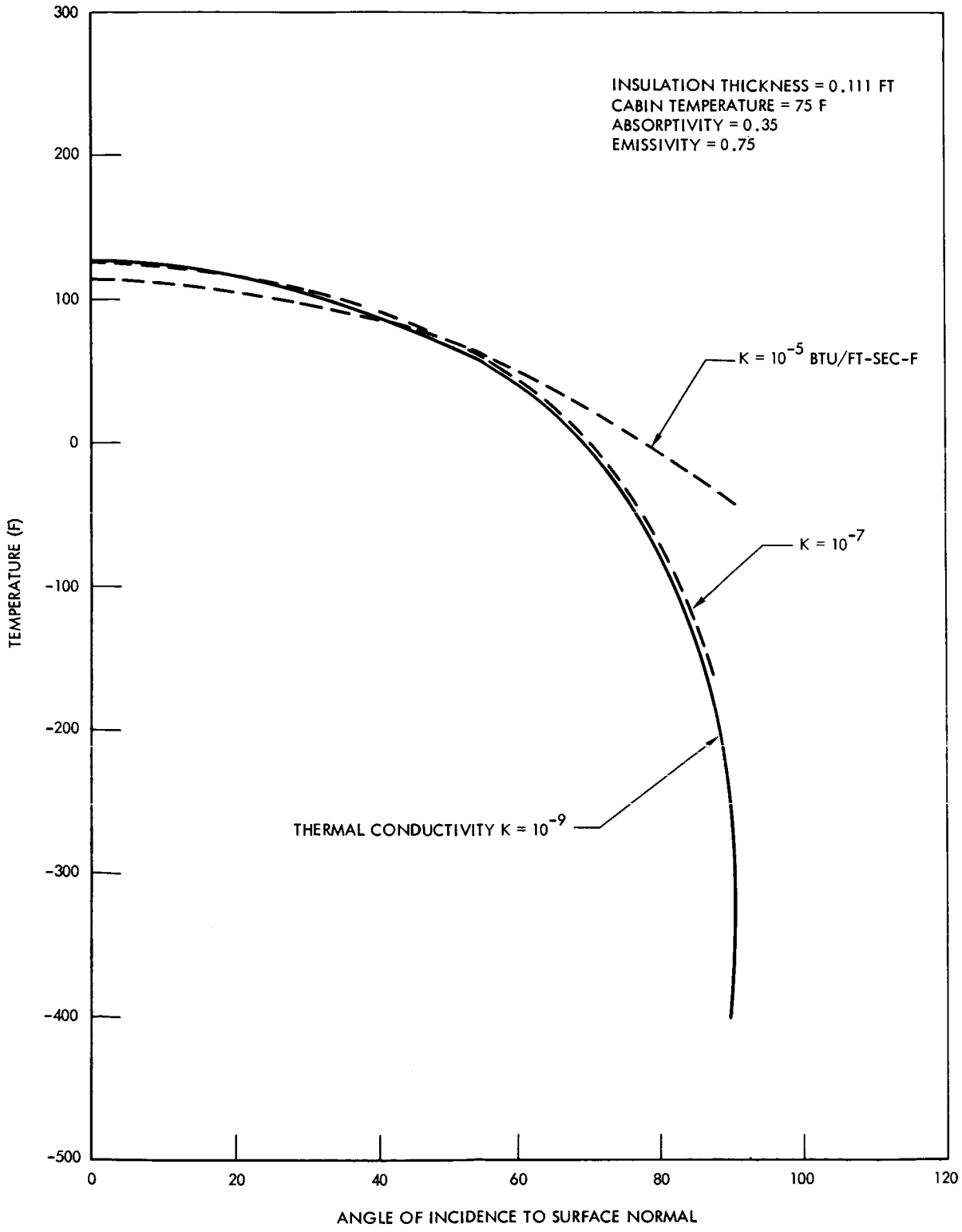


Figure 20. Surface Temperature Variation With Angle of Incidence of Solar Energy (White Paint)

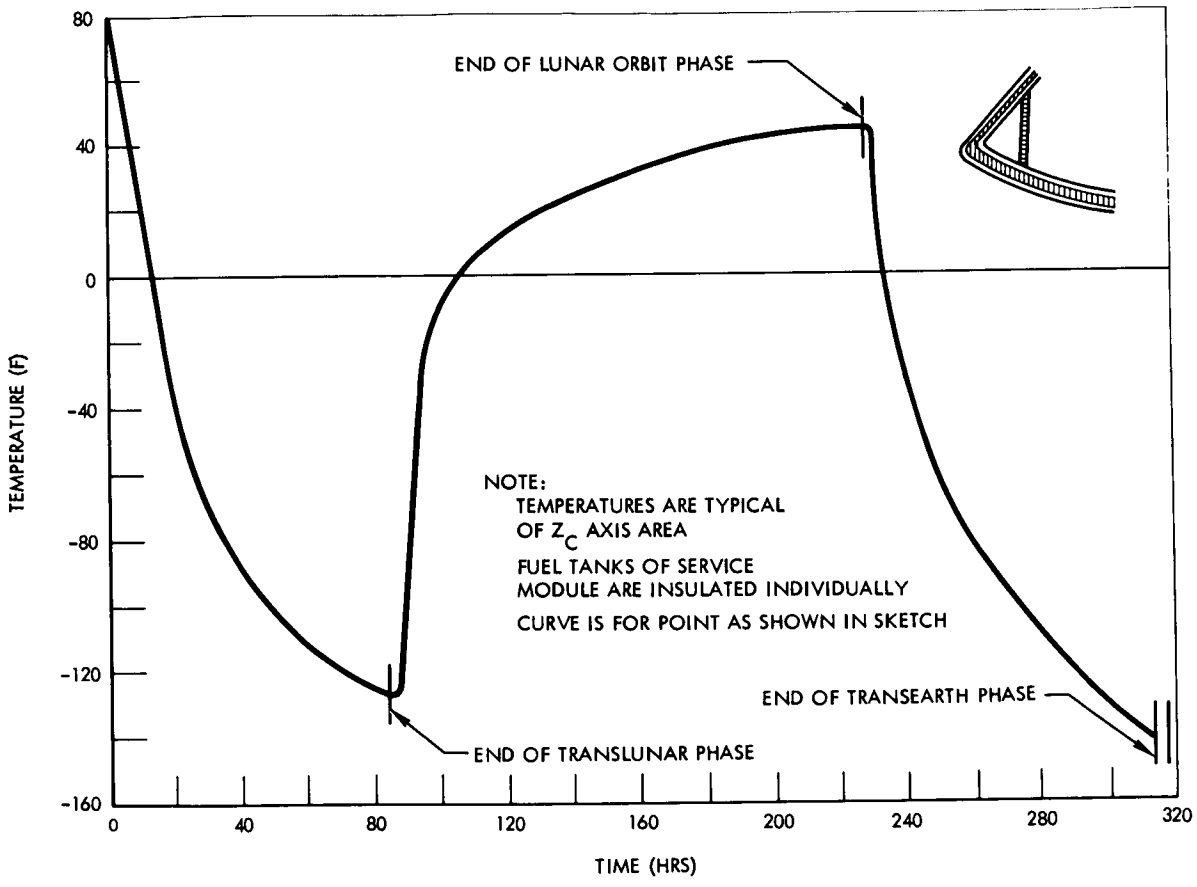


Figure 21. Stainless Steel Honeycomb Temperature During Space Mission Phases

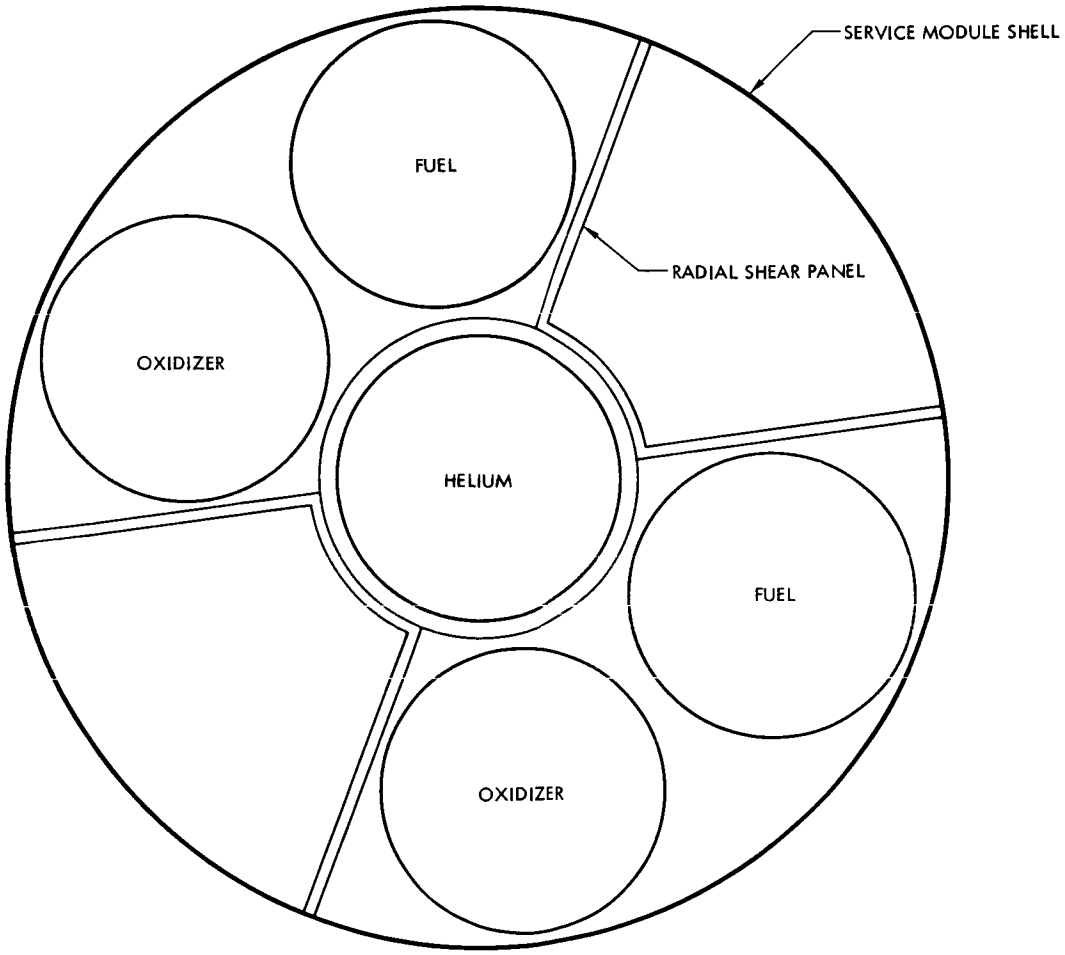


Figure 22. Service Module Cross Section Used for Analysis (Two-Dimensional Model)

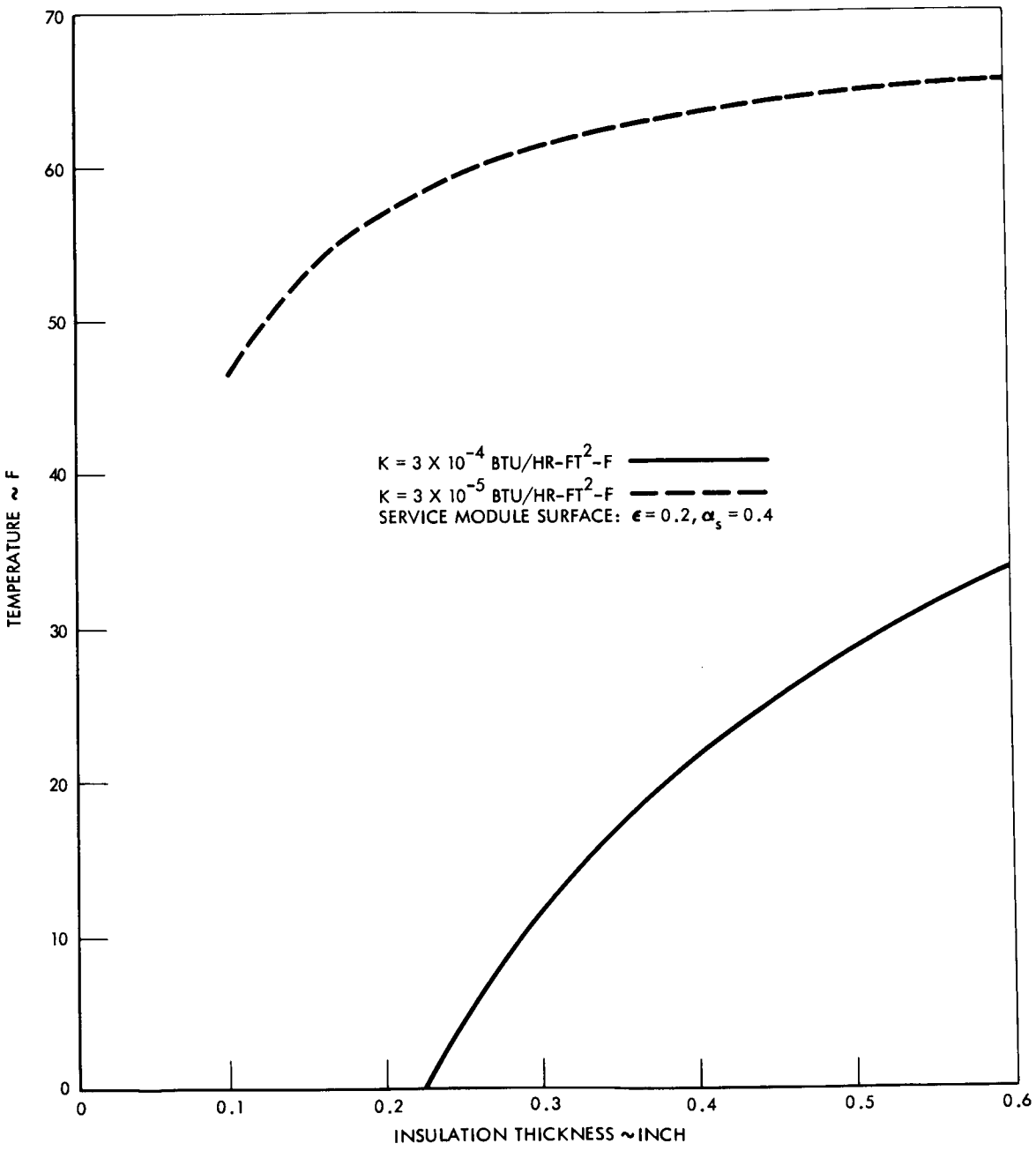


Figure 23. Fuel Temperature vs Insulation Thickness at End of Transearth Phase (Insulation Around Service Module Shell)

A parametric investigation determined the insulation requirements for the service module main engine propellant lines (2 inches in diameter) during the earth orbit, circumlunar, and lunar-orbit mission phases.

Two separate cases were considered in this analysis. In the first case, the propellant lines were assumed to be radiating directly to outer space. Results of this study are depicted in Figures 24 , 25 , and 26 . In the second case, the propellant lines were assumed to be radiating to a meteoroid shield having 0.5 inches of insulation. The shield, in turn, would radiate to outer space. Results of this study are shown in Figures 27, 28 , and 29 .

The heating requirements for the service module main engine injector plate during the translunar, lunar-orbit and transearth phases of the lunar mission are reported in Figures 30 and 31 . Figure 30 shows the heating requirement of the injector plate when the insulation of the service module is placed on the inner wall. Figure 31 presents the heating requirements when the service module insulation is placed on the main engine propellant tanks. A significant reduction can be seen in the power requirements when the emissivity of the injector plate surface facing the propellant tanks is reduced from 1.0 to 0.3.

## ENVIRONMENTAL CONTROL SYSTEMS ANALYSIS

### Temperature and Atmospheric Composition Control

A detailed analysis of the suit circuit including hand-calculated performance and schematics was presented in the previous quarterly report. The suit circuit has now been programmed for the computer to assist in the analysis of this system.

Work was begun to incorporate compressor maps into the computer program to replace the present expressions used to obtain volumetric flow rate and power input. The compressor maps will make the program independent of inlet pressure. A balance between the maps must be obtained, however, before the computer program can be supplied with the compressor inlet flow rate and power input.

Action was also taken to include relative humidity, oxygen flow rate, and water vapor flow rate as program data outputs for several pertinent points within the system.

### Water Glycol Circuit

A computer program was prepared to assist in the analysis of the water-glycol circuit. Required input data are the heat load at each heat

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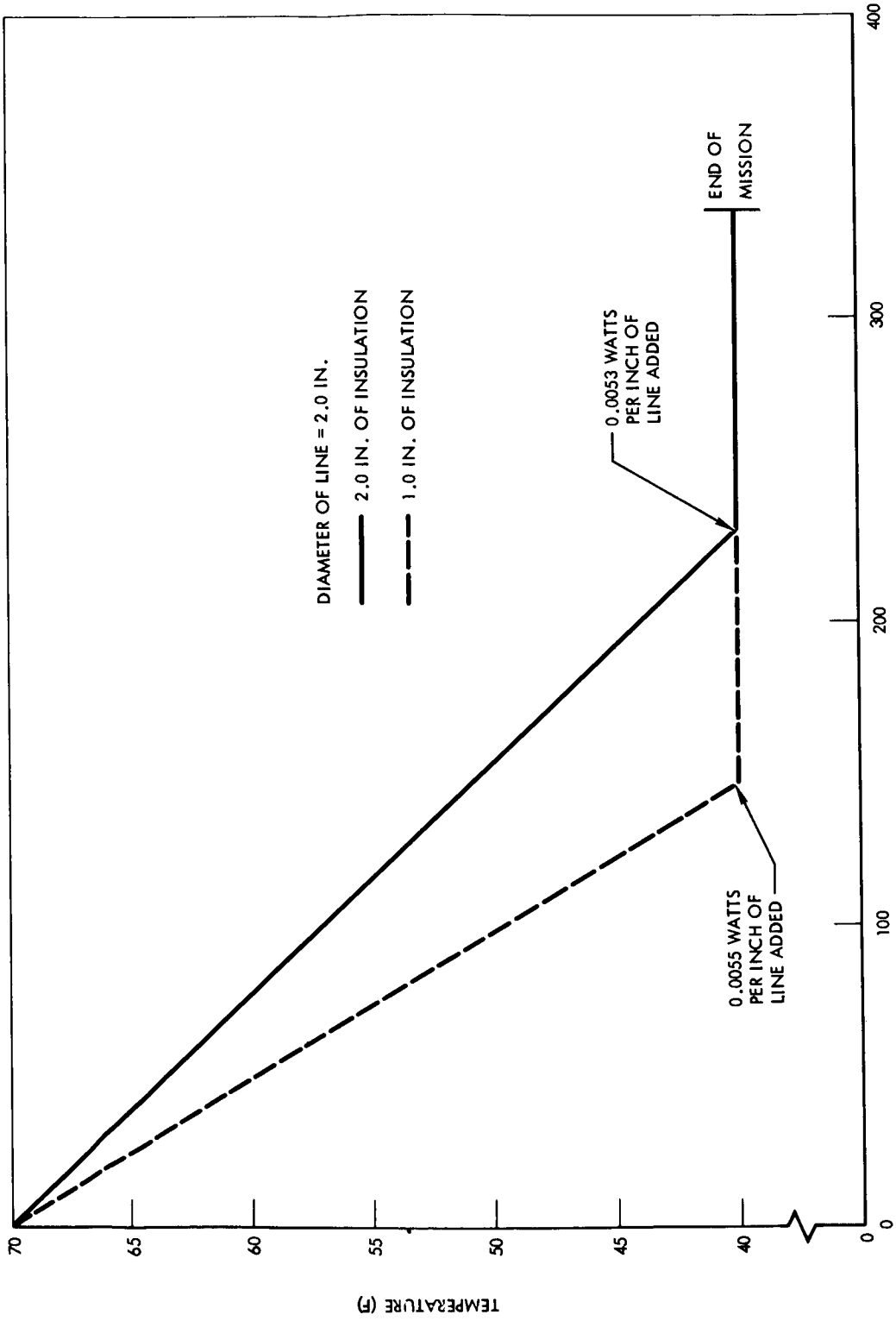


Figure 24. Service Module - Main Propellant Lines; Earth Orbit Flight

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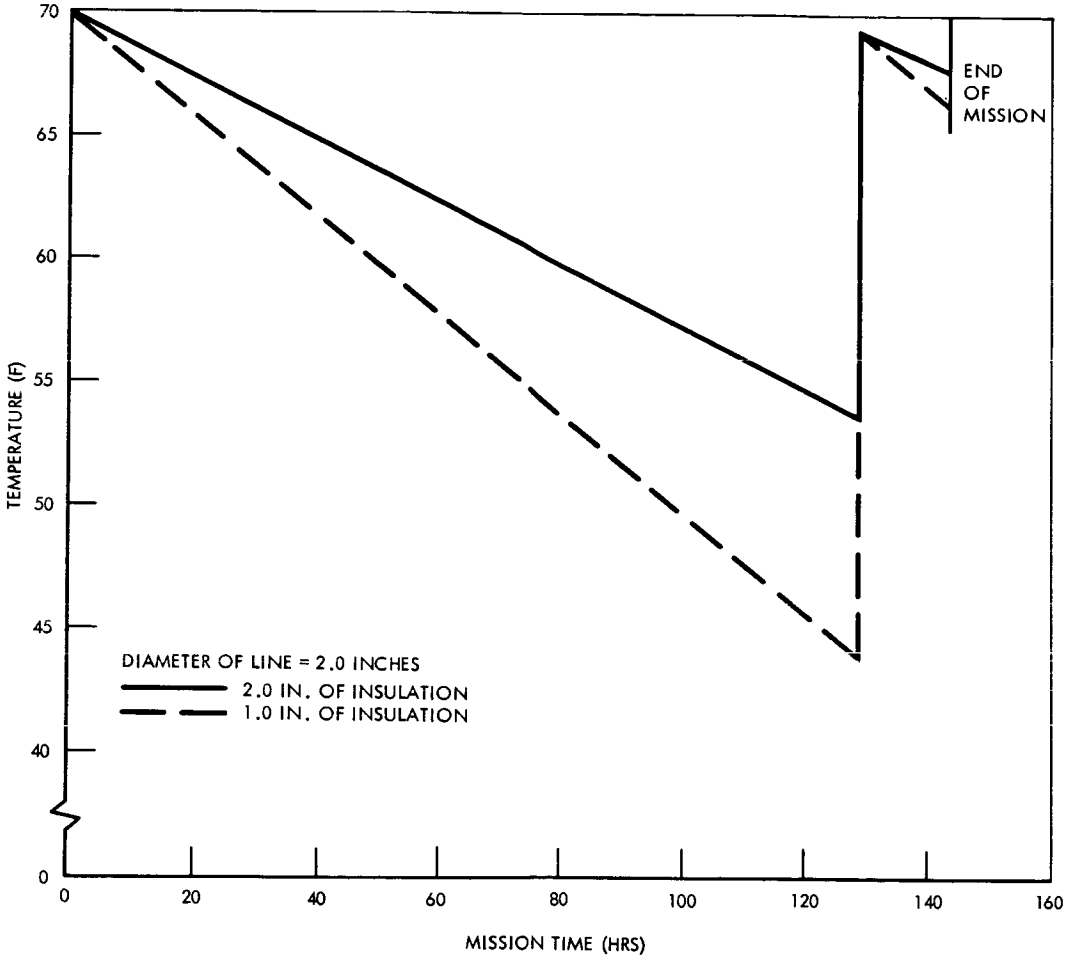


Figure 25. Service Module - Main Propellant Lines; Circumlunar Flight

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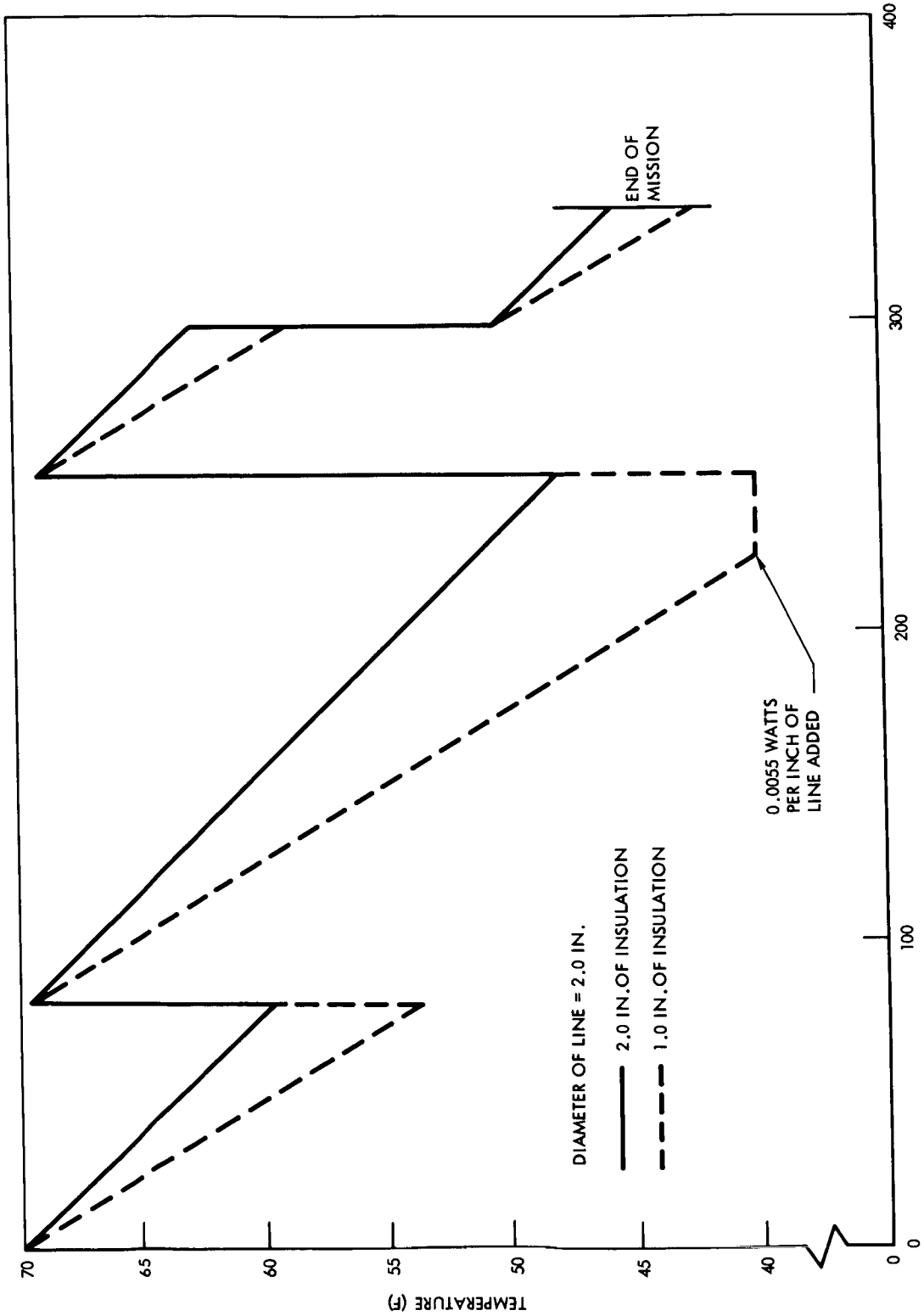


Figure 26. Service Module - Main Propellant Line; Lunar Orbit Flight (A)



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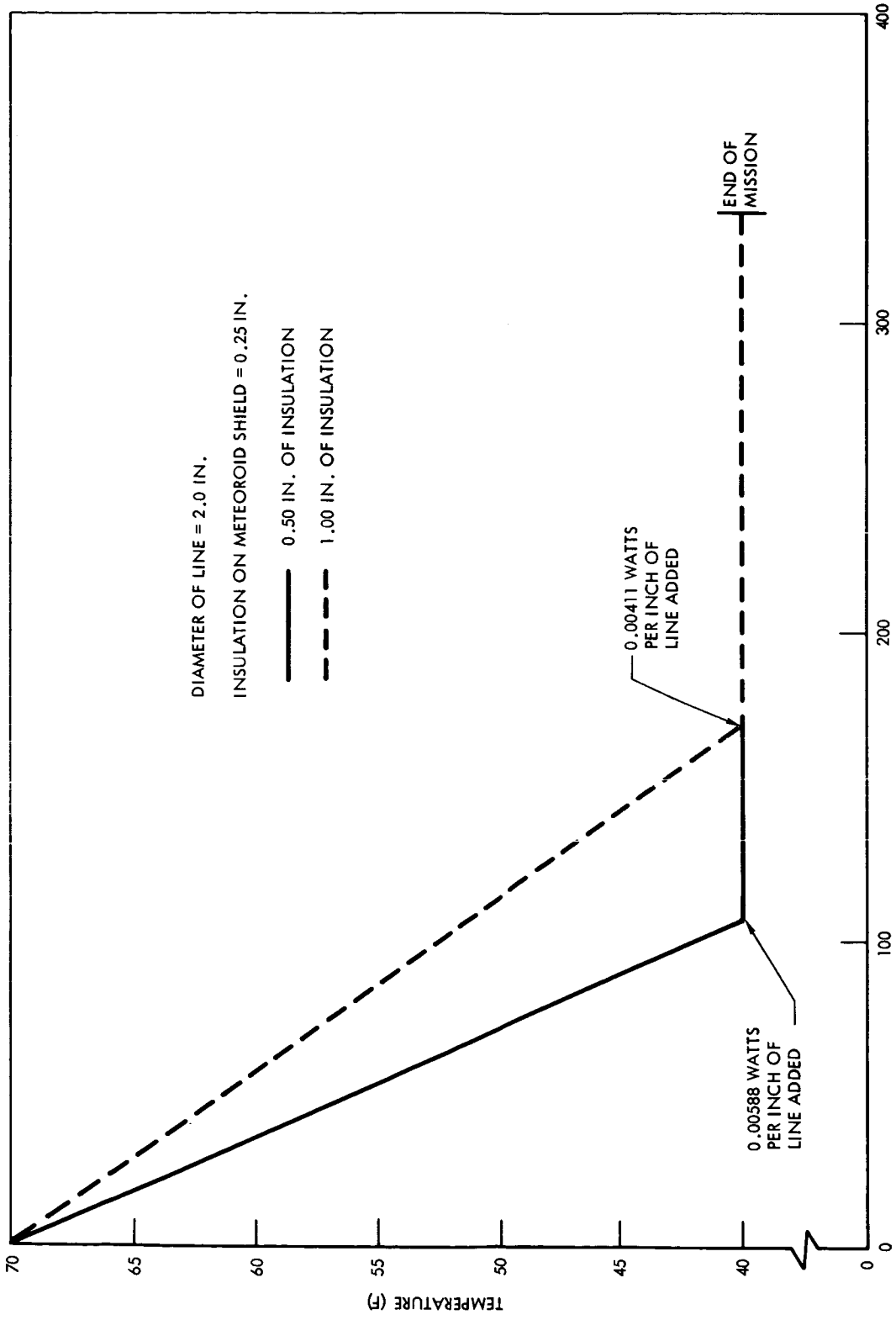


Figure 27. Service Module - Main Propellant Lines; Earth Orbit Flight

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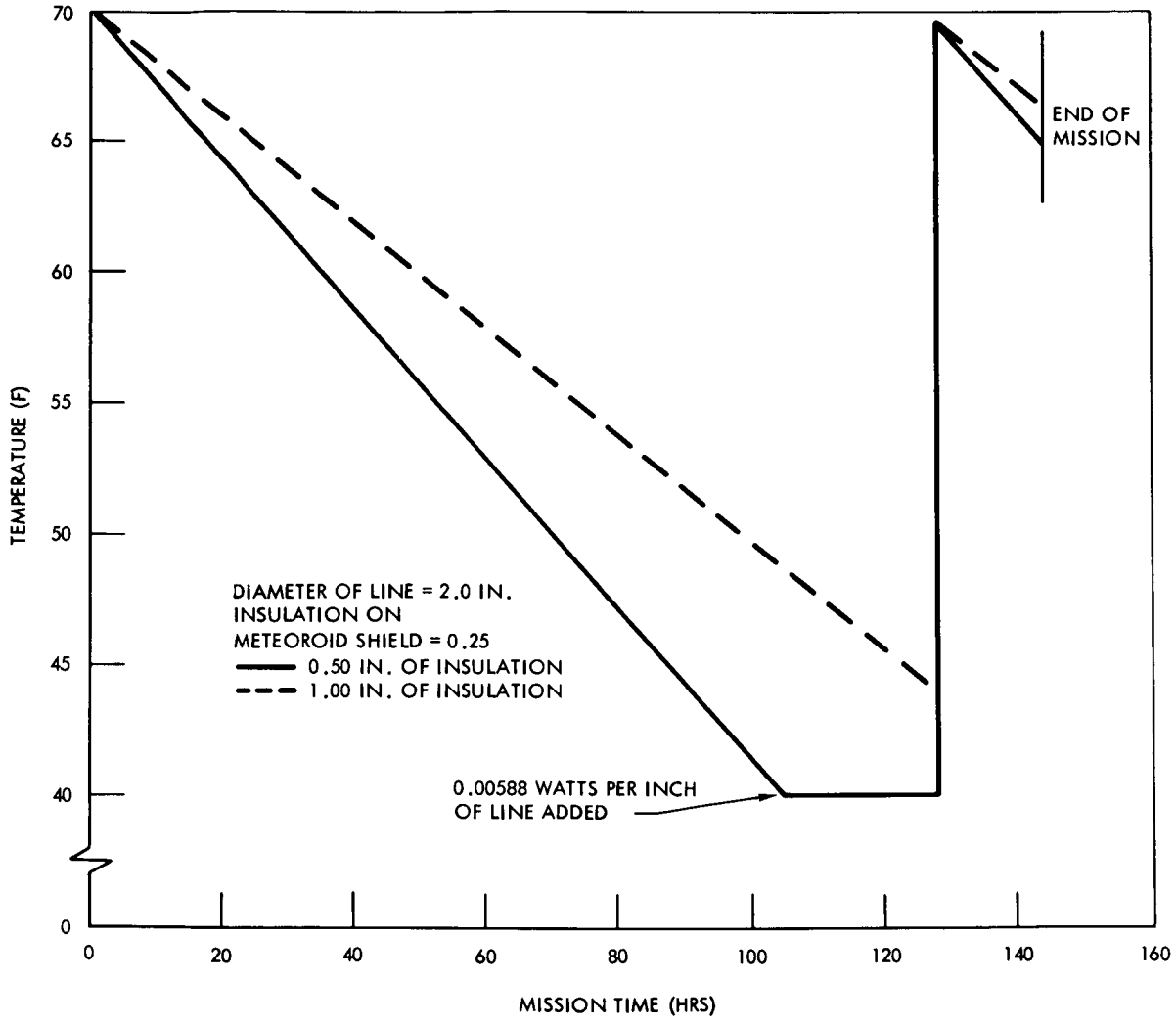


Figure 28. Service Module - Main Propulsion Lines; Circumlunar Flight



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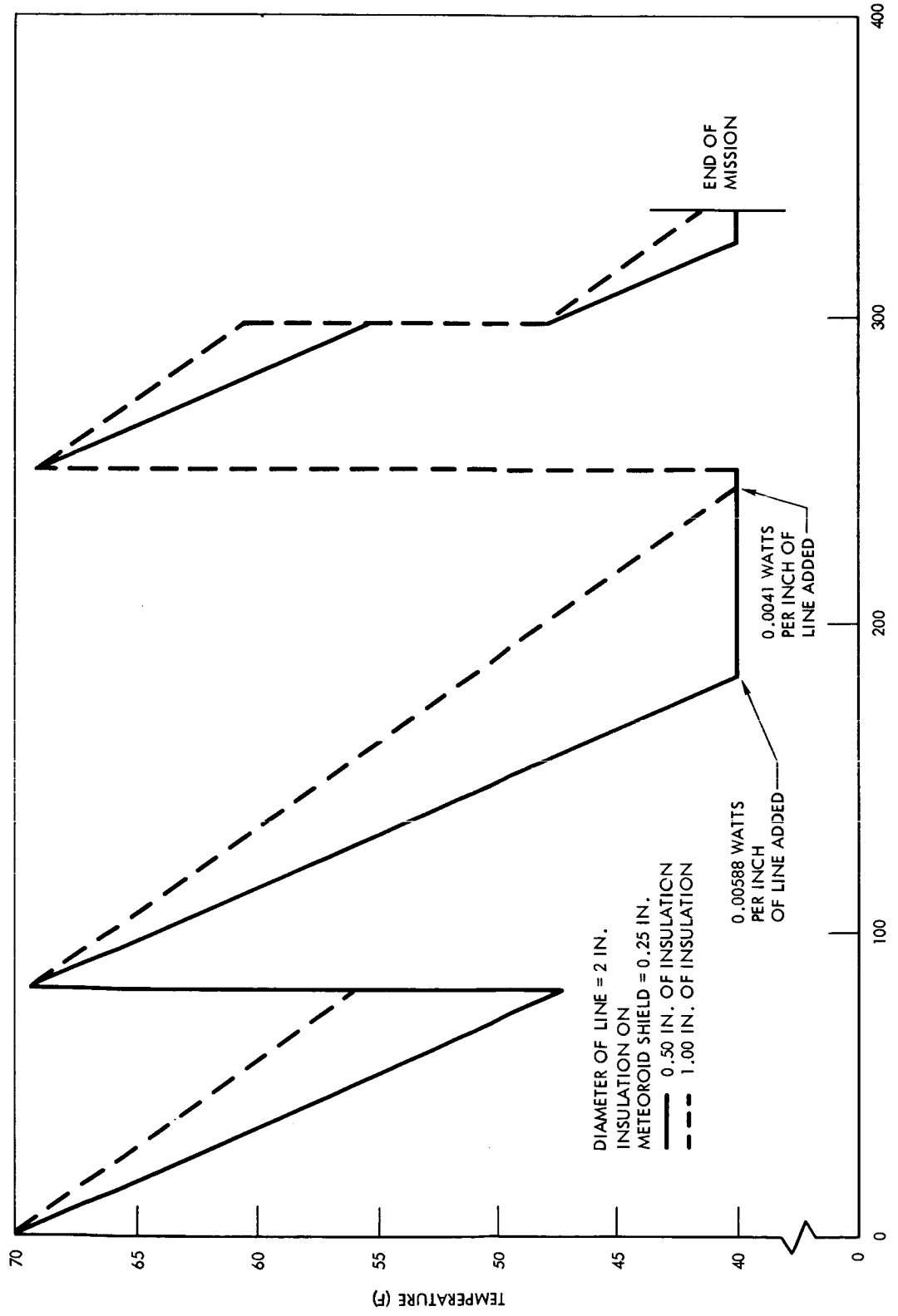


Figure 29. Service Module - Main Propellant Lines; Lunar Orbit Flight (B)



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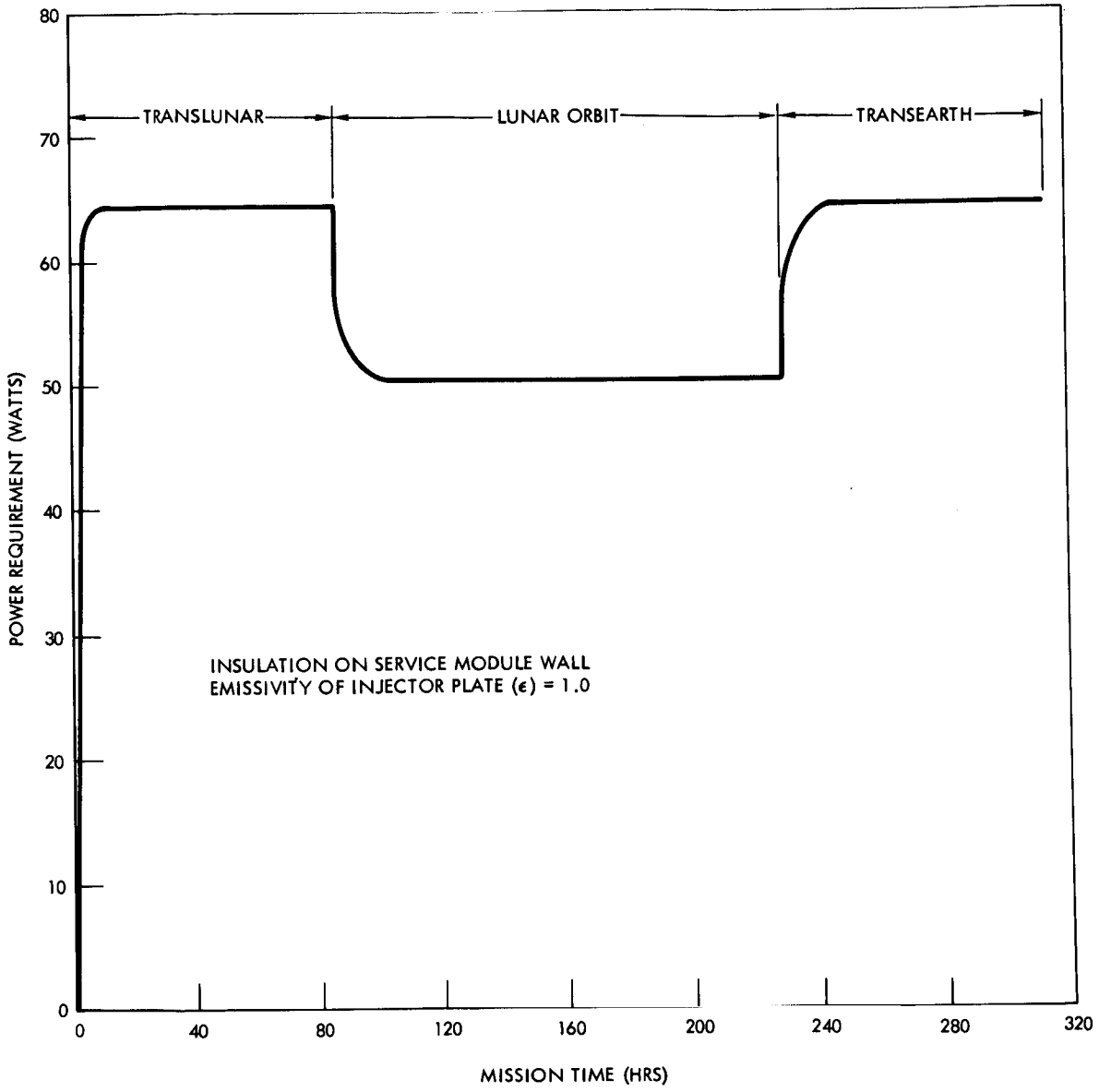


Figure 30. Service Module - Injector Plate Heating Requirements (A)

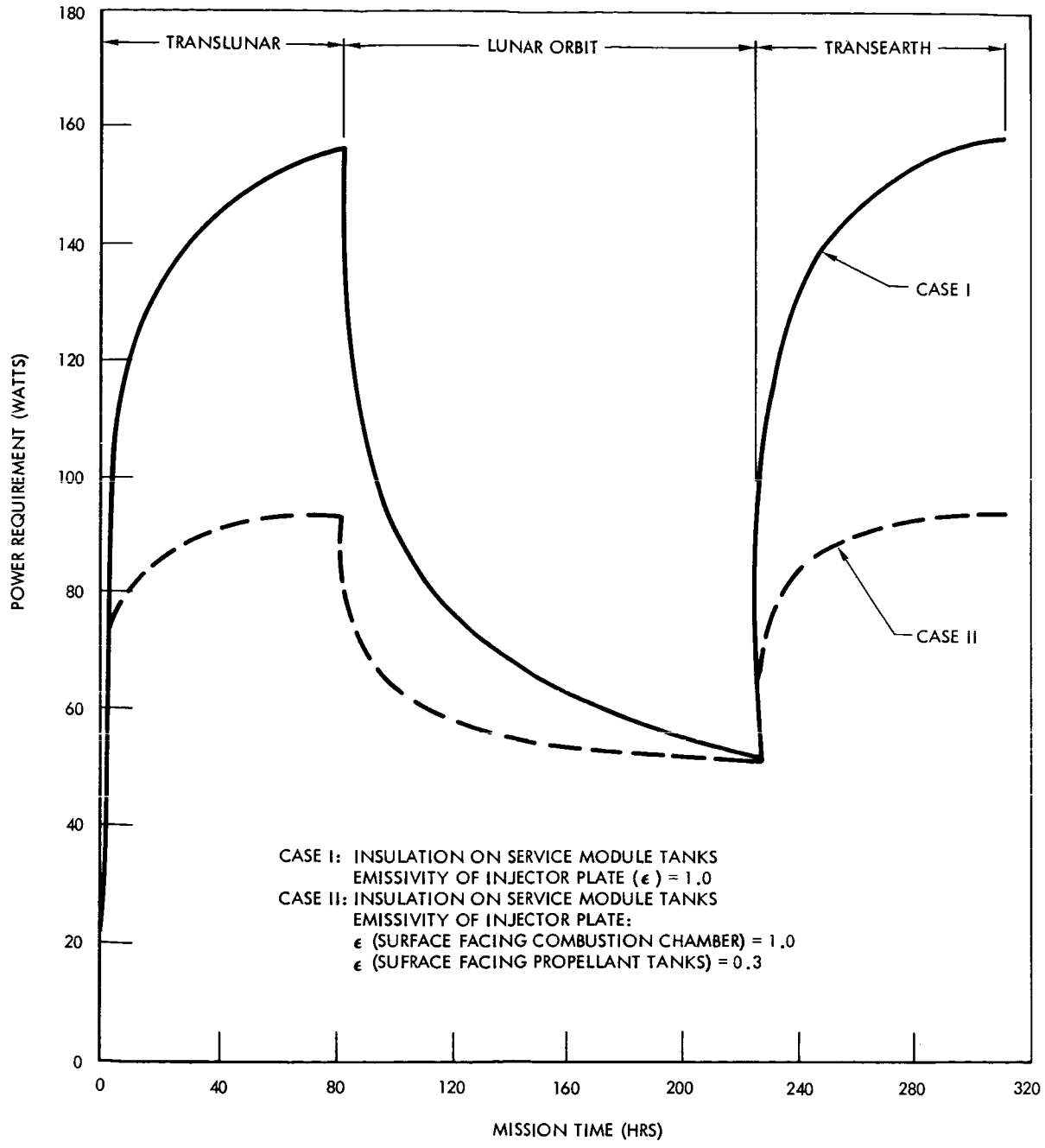


Figure 31. Service Module - Injector Plate Heating Requirements (B)

exchanger, the heat through the cabin walls, the physical dimensions of the radiator, and the external environmental heat absorbed by the radiator.

Figure 32, a schematic of the water-glycol circuit, shows the symbols used for the various output data.

Waste Management System

Pressure-drop calculations were continued to reflect system changes. Calculations indicate satisfactory system performance for the present configuration, which includes a new all-in-one selector valve, omission of several check valves, actual line lengths, and a 5-psia, 100-percent oxygen atmosphere.

Calculations indicate that the energy of the entraining air flow will be sufficient to flow the urine into the urine separator even at 1/6 g. Also, that the urine separator sponge will retain approximately 85 percent of urine volume under the same extreme conditions.

Water Management System

An analysis of the water management schematic indicated that no provision had been made to supply an adequate amount of hot potable water for food preparation and other purposes. Installation of an electrical heater in the water supply valve to supply instantaneous hot water was investigated; however, the electrical load (5 kw) was considered excessive. It was decided that the most feasible method was to provide a small hot-water reservoir of 2.5-pound capacity with a 45-watt heater. This size was based on the extreme condition of three men eating within 3 hours and each man consuming 2 pounds of water per meal.

An analysis was made to determine the approximate size of the water chiller. The dimensions indicated by AiResearch (6 inches long by 1 inch diameter) were confirmed.

The water time history computer program was developed to determine the water produced or consumed during each phase of the mission. The net increase will be added to the cumulative water on board. When the cumulative water on board exceeds 120 pounds, the net water produced will be dumped. The cumulative water (dumped) will then be totaled. When the net water produced is negative, the cumulative water on board will be decreased, and the water dumped will be zero.

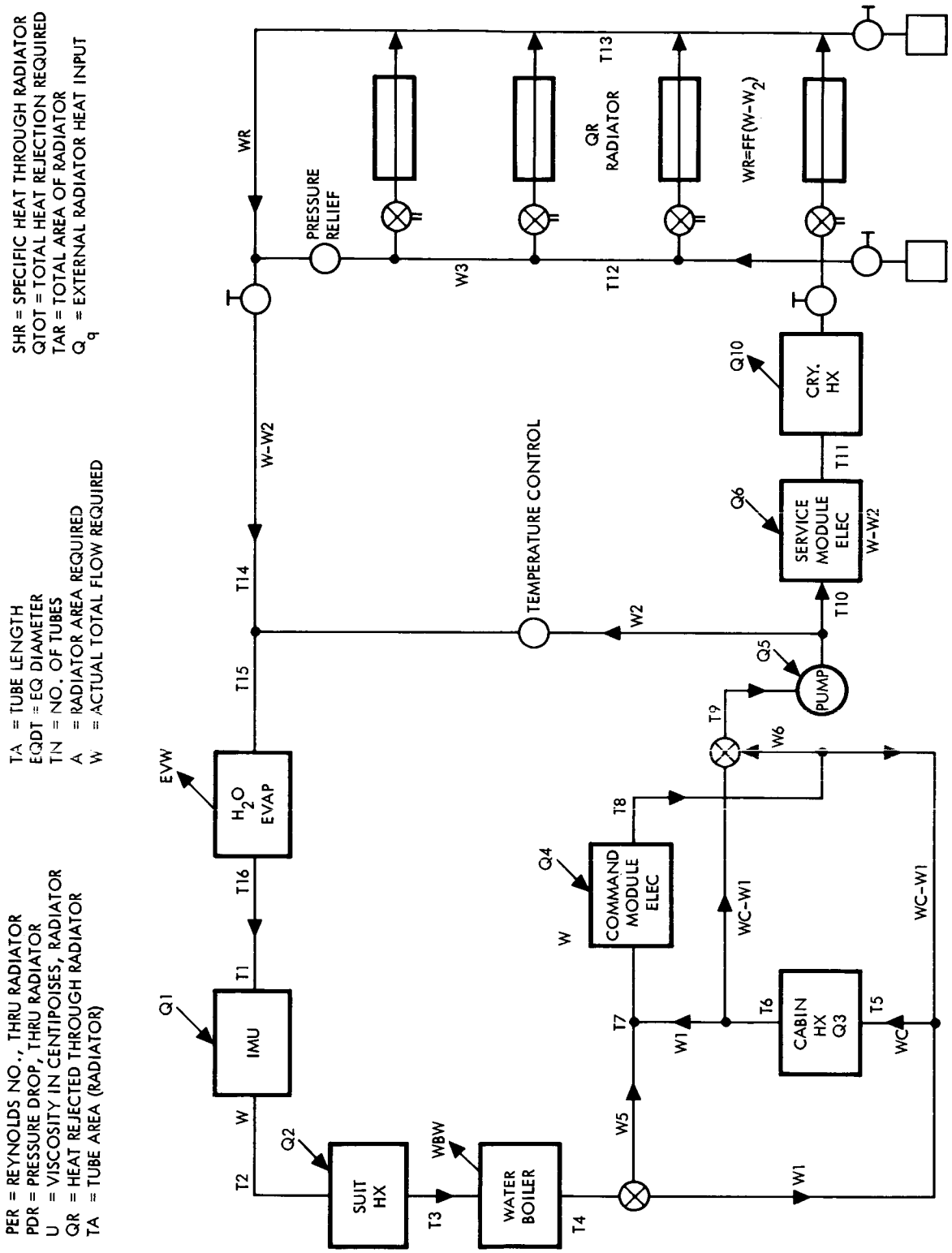


Figure 32. Water Glycol System

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## Fire Hazard Study

A study was initiated to investigate the fire hazard problem in a 5-psia oxygen atmosphere. In mixed atmospheres, the fire hazard is appreciably increased only when the partial pressure of oxygen exceeds 0.6 atmosphere. In a test in which fire hazard was expressed in terms of burning rate, the fire hazard for oxygen at 15 inches of mercury was half as great as that at 25 inches of mercury. The fire hazard, expressed by combustion time, decreases with a decrease in oxygen partial pressure. This test was conducted with cotton twill as the combustible material. The ratio of burning rates might vary with combustible materials.

## Atmospheric Contaminants Analysis

As part of a weight-saving study, the carbon dioxide absorber requirements were investigated. The two main determinants governing the quantity of carbon dioxide produced, and consequently the amount of lithium-hydroxide required for carbon dioxide removal, are respiratory quotient and oxygen consumption.

The metabolic requirements, as outlined by NASA, define a respiratory quotient of 0.93. It is felt that this is not representative of an average respiratory quotient. A more realistic value would be 0.85.

An analysis is under way to determine the heat loads and pressure drops in the water-glycol system during ground cooling. The purpose of this evaluation is to determine the adequacy of the refrigeration and pumping stages of the service unit. Sizing and insulation of the umbilical lines are receiving special attention in this analysis.

## Condensation and Cooling Analyses

The problem of moisture condensation on the ECS ducting is being investigated. If the amount of condensed water is considered a problem, suitable insulation will be determined as well as a limited zero g test program.

Various methods of cooling the command module are under study and consider the possibility of a 2-hour hold time after countdown before launch. Preliminary results indicate a weight and complication penalty if this becomes a design requirement.

## Unmanned Spacecraft Cooling Analysis

Studies made of instrumentation cooling requirements for boilerplates 12, 13, 15, and 21 indicated that a system providing both ambient air and

coldplate cooling would be required. Ambient air cooling would be necessary during ground operation and launch, for the instrumentation that cannot be coldplate cooled. The coldplate cooling would be necessary during ground operations, launch, and orbit and for the telemetry and C-band transponder. Predicted ambient air temperatures with and without cooling during launch are shown in Figure 33

Leakage rate studies indicated that a leakage area of 1/2 square inch would retain an air pressure within the command module equivalent to a 50,000-foot altitude at the time orbit is reached. This would be sufficient for the instrumentation requiring operation during this period. Since GSE can supply liquid cooling until the time of launch for boilerplate 6, no on-board storage tank will be necessary.

A detailed system and component analysis was made of some available off-the-shelf components suitable for use on the cooling system. Broad liquid and on-flow limits were established for the system components to permit the purchase of off-the-shelf components.

Analyses were completed of a basic cooling system. These included plates for some equipment, for pad abort, max q and early orbital vehicles.

Equipment Cooling Analysis and Test

The single coldplate analysis computer program was extended to provide coldplate surface temperatures that would reflect the larger electrical loads now reported. A comparison of analytical results from the computer program with those obtained from the first experimental coldplate is shown in Figure 34 . Satisfactory agreement is indicated.

The single coldplate computer program is being expanded to include the complete coldplate cooling system. Initial checkout runs are being made.

The weight penalty for the incorporation of redundance within the electronic cooling system has been analyzed for 33 possible system combinations.

Cooling performance tests were run on an adhesive bonded, honeycomb coldplate. Figure 35 is a photograph of the test set-up installed in the vacuum chamber. Interface conductance tests were run on various interface materials. The only materials providing satisfactory conductance values at both sea-level pressure and in a vacuum have been greases or grease-containing compounds.

Cooling requirements for such passively cooled electrical equipment as lights and panel meters are being analyzed.

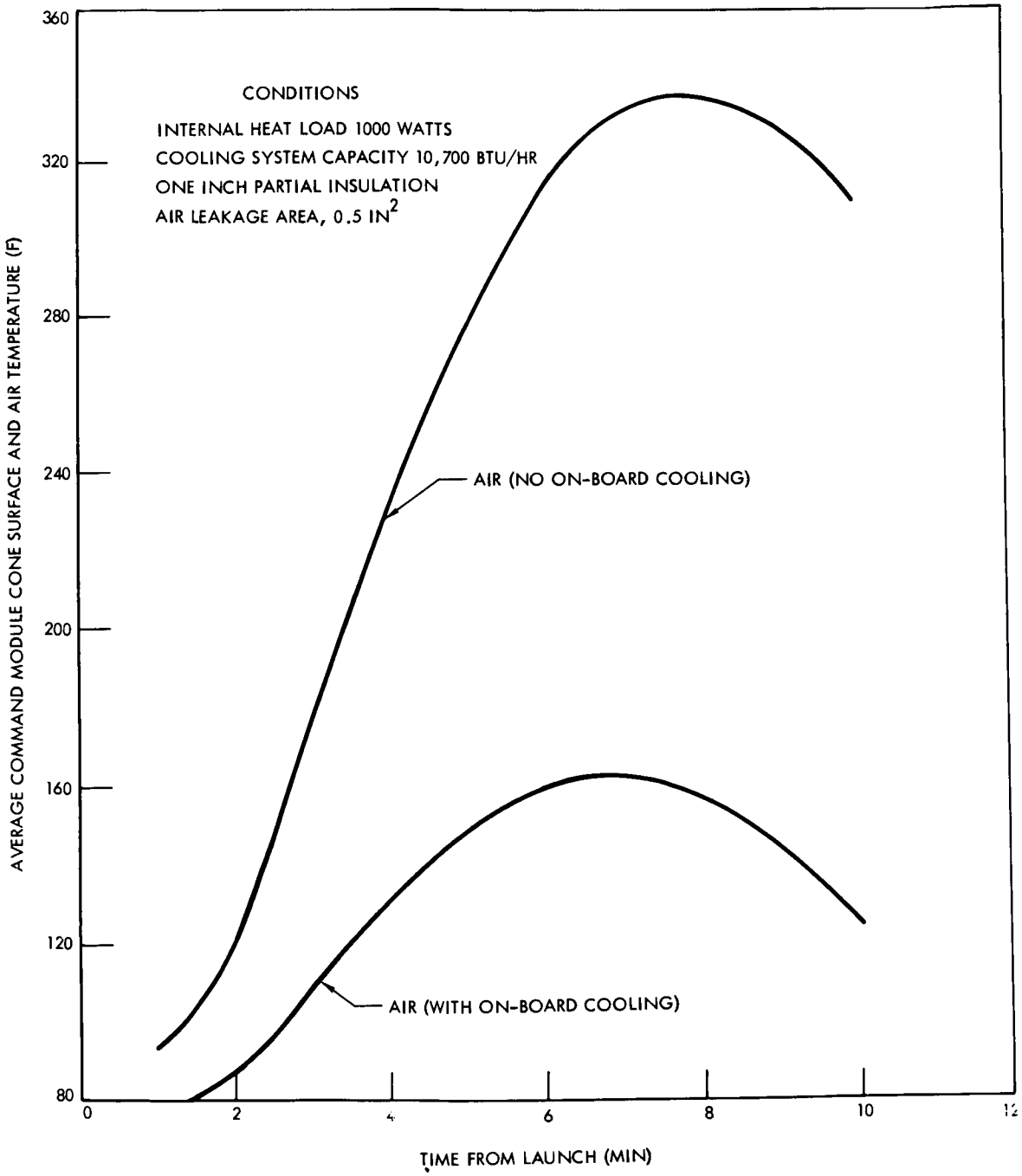


Figure 33. Boilerplate 13 and 15 Temperature Profile

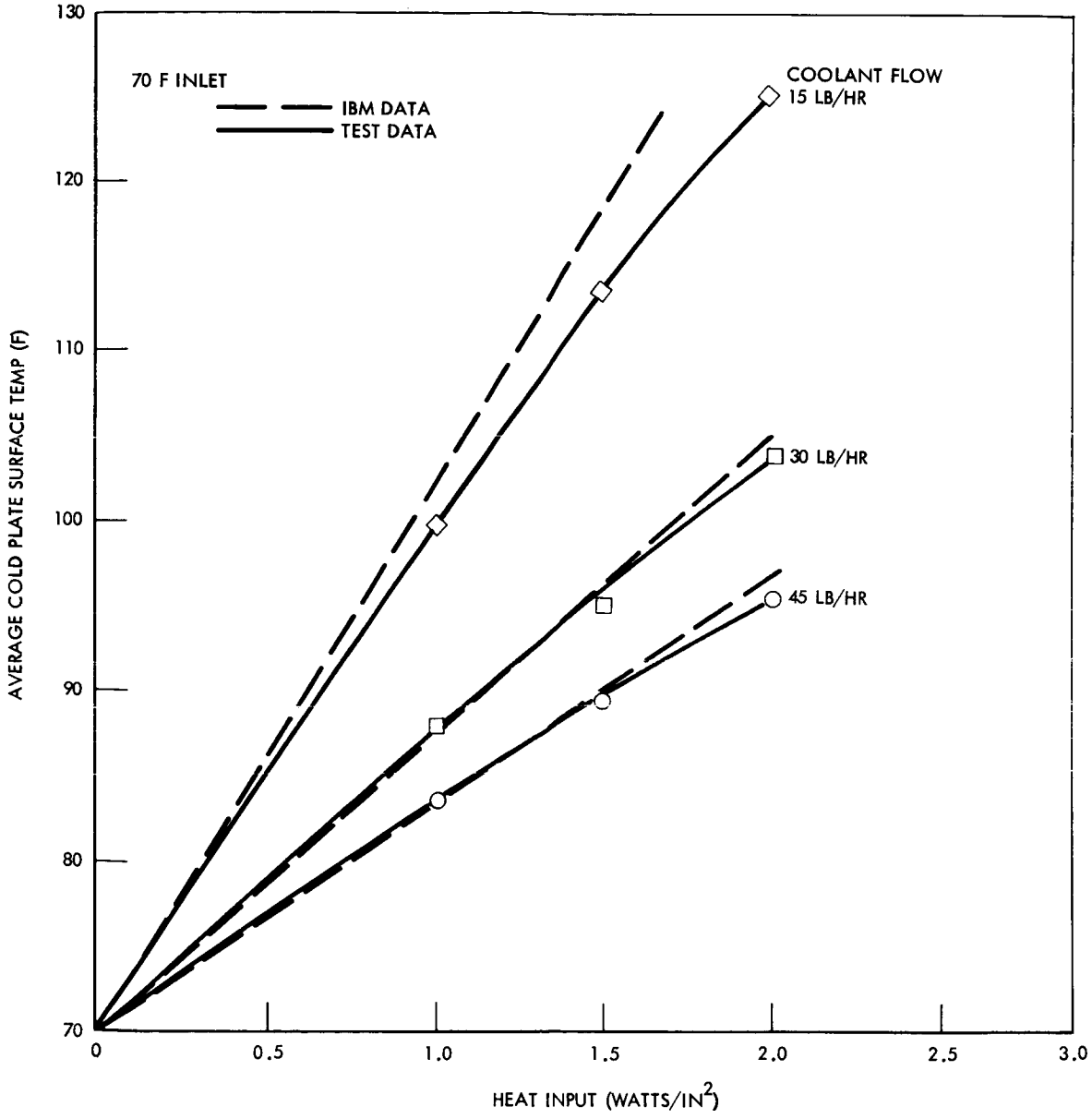


Figure 34. Coldplate Analytical vs Test Values

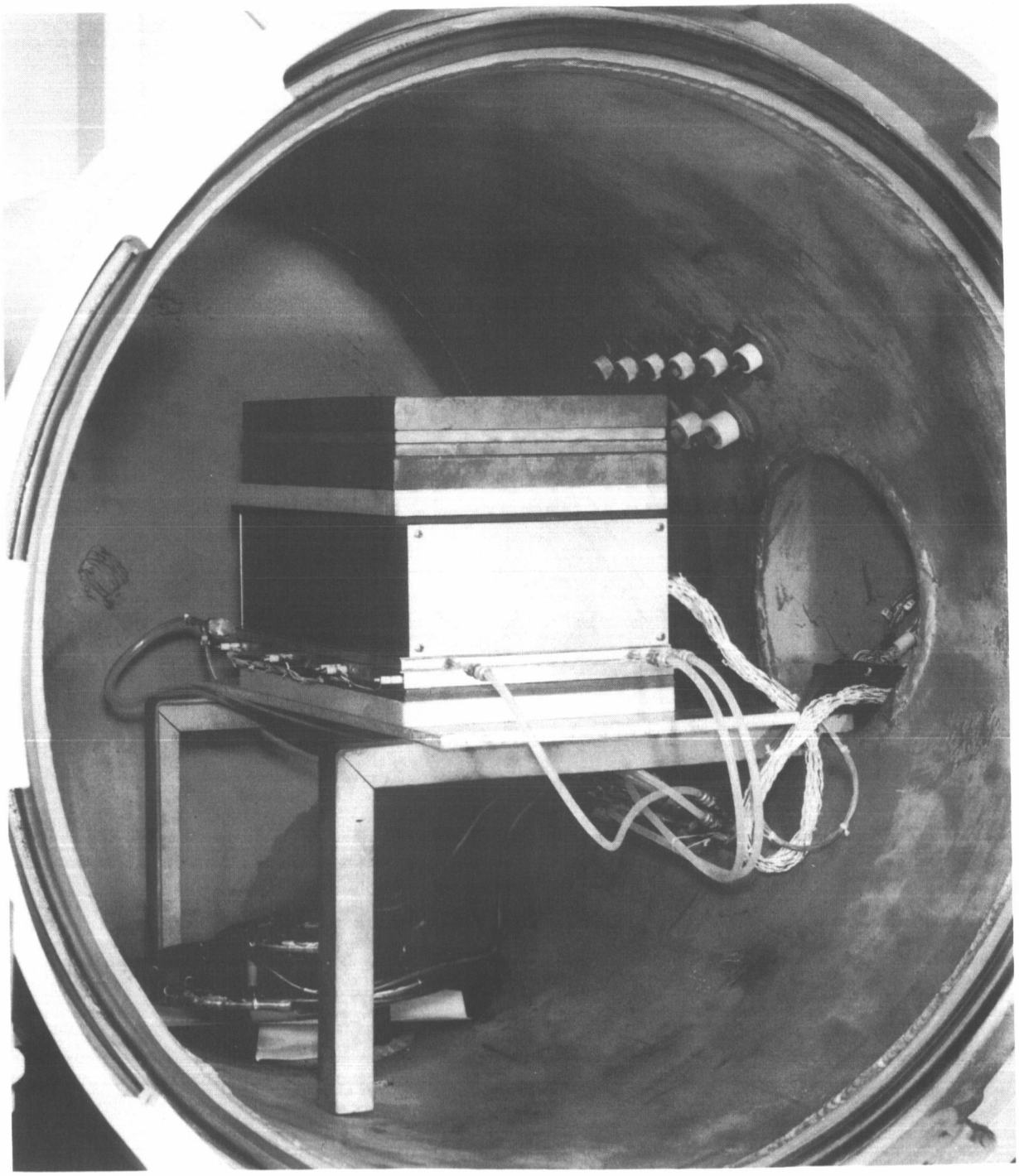

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Figure 35. Coldplate Test Setup Installed in Vacuum Chamber With Collins Simulated Electronic Module

POWER SYSTEMS ANALYSIS

## Space Radiators

The EPS radiator, as sized for one module emergency operation in lunar orbit, consists of a 48-square-foot area divided into six sections, two for each fuel cell module. Three sections, one for each module, are located on each side of the service module; the two sections for each module are in series.

Because of the different locations of the individual sections around the service module, the heat rejection and absorption rates are different for each section at a given location in orbit. A transient analysis of the radiator sections is expected to show that the actual maximum and minimum glycol outlet temperatures will be closer to inlet temperature than is now calculated. A sample curve showing the wide variance in glycol outlet temperature for the lunar orbit is shown in Figure 36.

With the elimination of the lunar landing mode, new ECS radiator sizing studies were made. These studies resulted in plots of heat rejection capacity versus position in orbit for three different size radiators. The amount of supplemental cooling available from water evaporation is being coordinated with radiator heat rejection capacity versus position in orbit for three different size radiators. The amount of supplemental cooling available from water evaporation is being coordinated with radiator heat rejection capacity to obtain the optimum size radiator. It is anticipated that earth-orbit conditions will determine the radiator size.

## Supercritical Gas Storage

Figure 37 illustrates the total heat input requirements for the cryogenic tanks during the entire mission. This curve is the summation of the heat inputs for the hydrogen and oxygen tanks, which have the same form as shown in Figure 37 and were developed from the specific heat input requirements multiplied by the instantaneous flow rates.

In Figure 37 heat input requirements are moderately high at the beginning and end of the mission and are modest during the majority of the mission. It now appears realistic to lower the end of mission requirements by allowing tank pressure decay.

The shaded area of Figure 37 represents heat leakage to the fluids through insulation, lines, etc. As the design becomes firm, it may be possible to arrange the insulation so that heat leakage is essentially the same as the minimum point of the required heat input.

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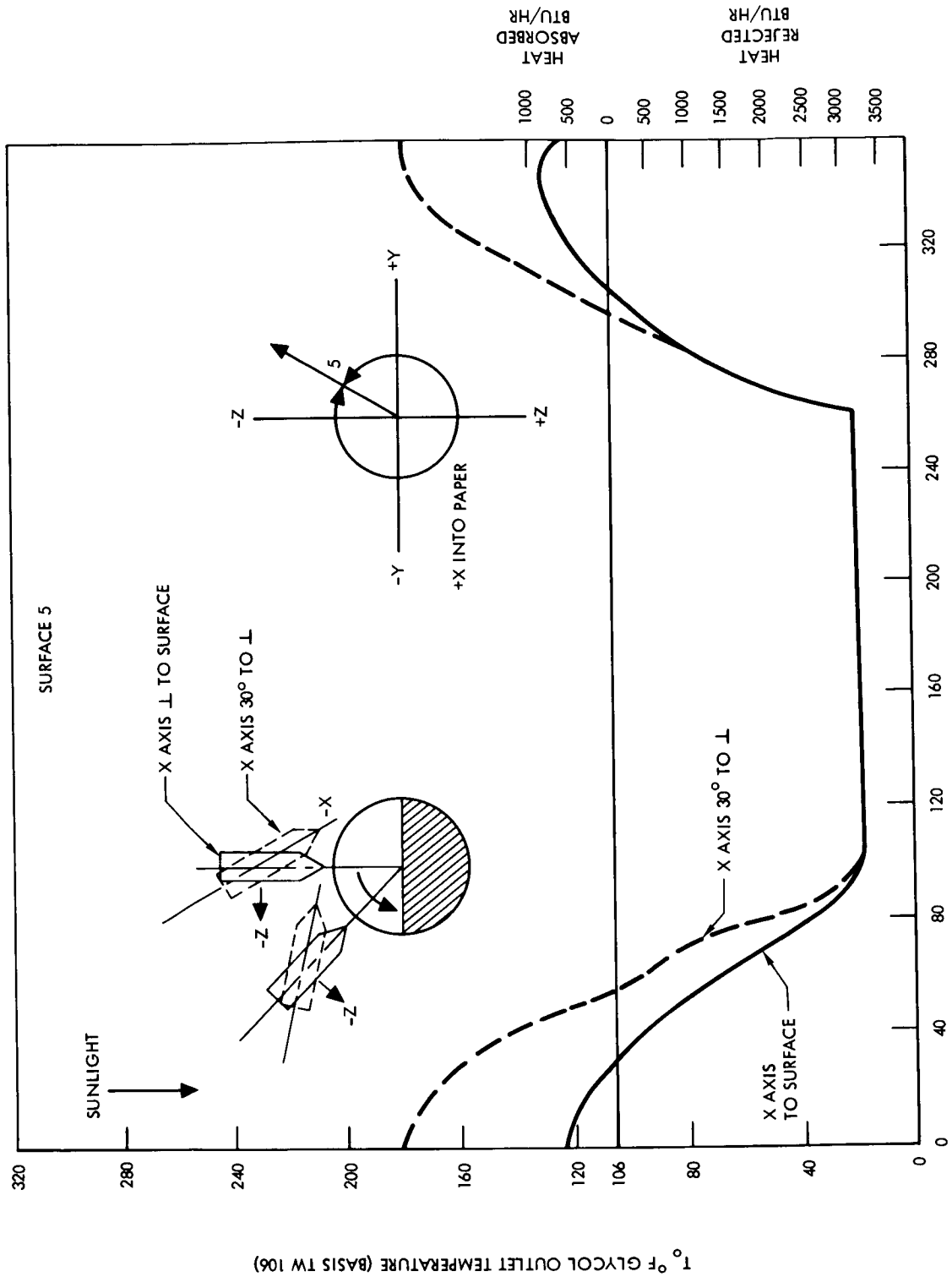


Figure 36. ECS Radiator Glycol Outlet Temperature for 50 Lb/Hr Glycol Through Section Totaling 29.5 $Ft^2$



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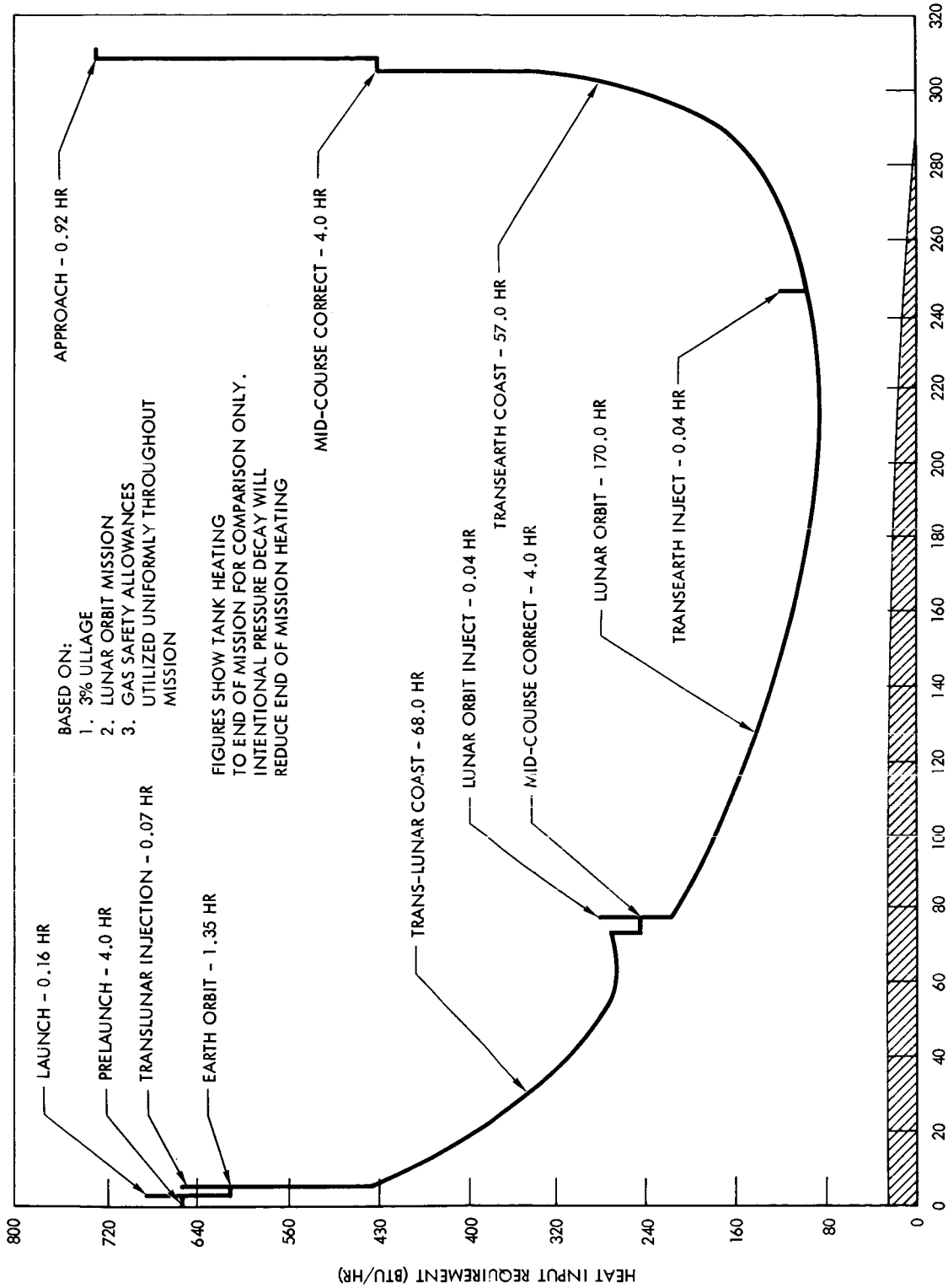


Figure 37. Supercritical Gas Storage Subsystem; Total Heating Requirements for Oxygen and Hydrogen Tanks

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Problem areas of ethylene-glycol-water ECS coolant were freezing of the cooling during emergency flow conditions, a tendency towards unbalanced heating of the tanks, and failure as a result of ethylene-glycol leakage. The following tabulation shows that weight of the two heating methods is about equal when the weight of the reactants required for the electric heaters is included.

| Glycol-Water Heating | | Electrical Heating | |
|---|---|---|---|
| Heat exchangers | 6.3 | Heaters and extended surface spheres | 7.9 |
| Plumbing and glycol | 6.9 | Reactants (16.5 khw), (0.866 lb/kw-hr) | 14.3 |
| Control valves | 1.0 | Vessel residual gases | 17.5 |
| Vessel residual gases | 24.9 | | |
| | 39.1 lb | | 39.7 lb |

Because of nearly equal weight penalties and the simplicity and greater reliability of electric heating, the electric arrangement has been adopted.

A preliminary analysis on cryogenic subsystem fill lines was completed. The cool-down time, cool-down weight, and pressure drop during cool-down and fill were calculated for several flow rates for a vacuum-jacketed line.

An analysis was performed of gas heating within the pressure vessel by means of heat addition at the pressure vessel. Figure 38 illustrates the difficulty in raising oxygen gas temperature 1 inch from the wall within a reasonable period of time. This slow temperature rise is primarily a function of the low thermal diffusivity of the stored gas. As a result of this analysis, an internal heat exchanger consisting of a series of thin-wall concentric spheres, each a prime heating surface, is being considered.

## Fuel Cell

Calculations were completed of the cool-down times required for removal of the fuel cell during prelaunch checkout.

The results indicate that 15 hours will be required to cool the module to 200 F.

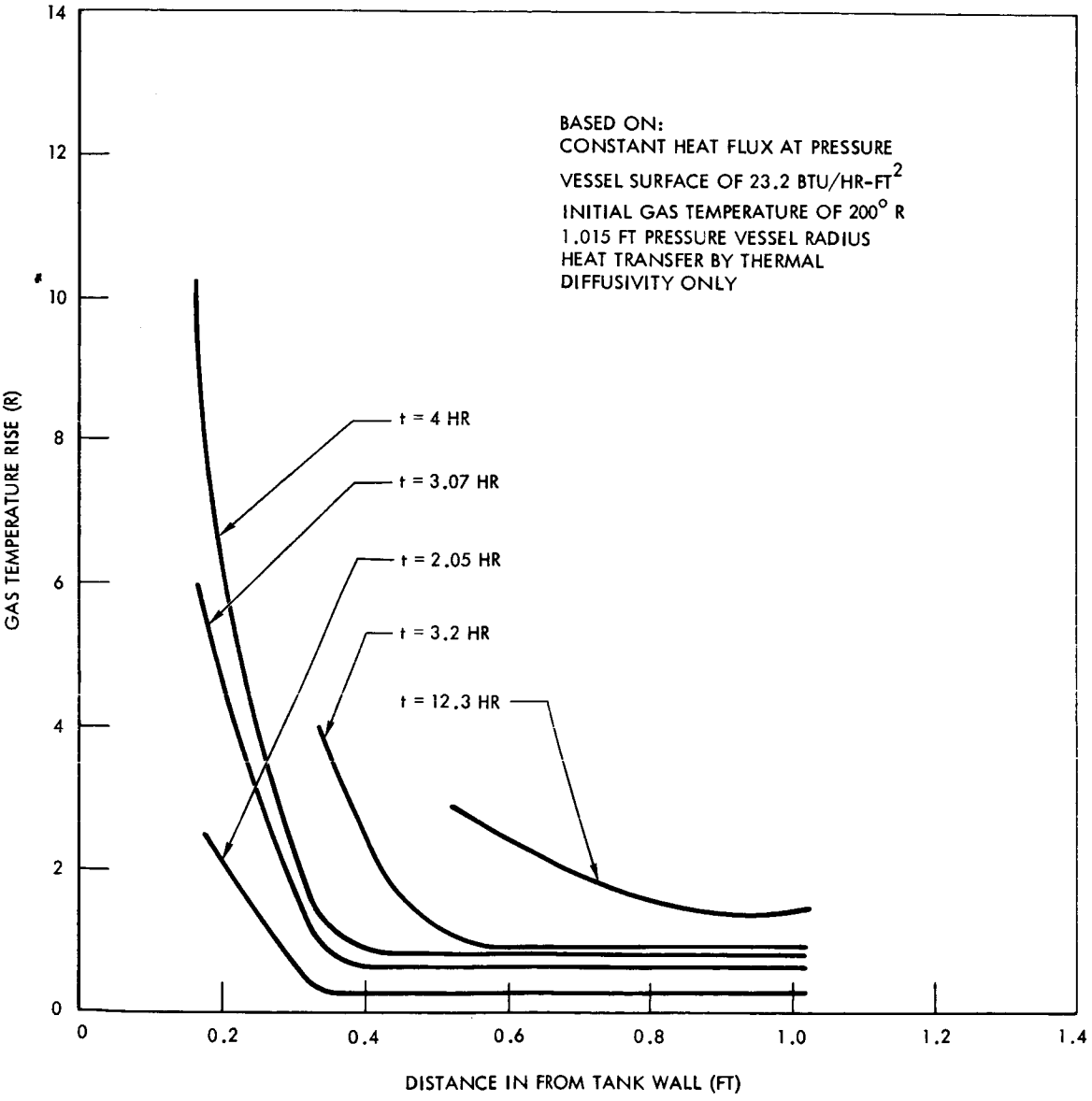


Figure 38. Supercritical Gas Storage Subsystem; Temperature Rise of Cryogenic Oxygen When Subject to Heating at Pressure Vessel Wall

## PROPULSION SYSTEMS ANALYSIS

### Engine Systems

#### Reaction Control Systems, Command Module

Analyses were conducted to determine the effects of the Apollo reentry convective heat transfer values on the semiradiation-cooled RCS engine design for the command module. The results showed engine component temperatures reached excessively high values. They also indicated the existence of two major problem areas in the command module engine design, either of which would eliminate the semiradiation-cooled engine concept from further consideration for Apollo. These two problem areas are excessive wall temperatures in the divergent portion of the nozzle (Figure 39) and excessive temperature of the fuel (Aerozine-50) in the cooling coil (Figure 40).

The initial temperature of the thrust chamber was assumed to be 3000 F (Figures 39 and 40), at which time the reentry heating rates were applied to the thrust chamber. The reentry heating rate temperatures used in the study were for the undershoot reentry trajectory and the 92-degree yaw engines (closest to stagnation point). Figure 39 also shows that the nozzle can reach a temperature of 3800 F (at approximately 65 seconds), which is in excess of the allowable temperature limit (3000 F for coated molybdenum).

Figure 40 indicates that the temperature of the quiescent fuel in the engine cooling coil could reach a temperature as high as 605 F.

The use of all-ablative RCS engines in the command module was recommended, and studies of the various aspects of ablative thrust chambers were undertaken.

A study was initiated to compare an optimum Apollo ablative engine with the present design and performance characteristics of a 100-pound thrust ablative Gemini engine.

#### Reaction Control Systems, Service Module

An analysis of the radiation heating effects on the service module structure nearest the RCS engines (shown perpendicular to the centerline of the service module RCS engine in Figure 41) indicated that the surface temperature rise due to engine operation was a strong function of the structural material emissivity.

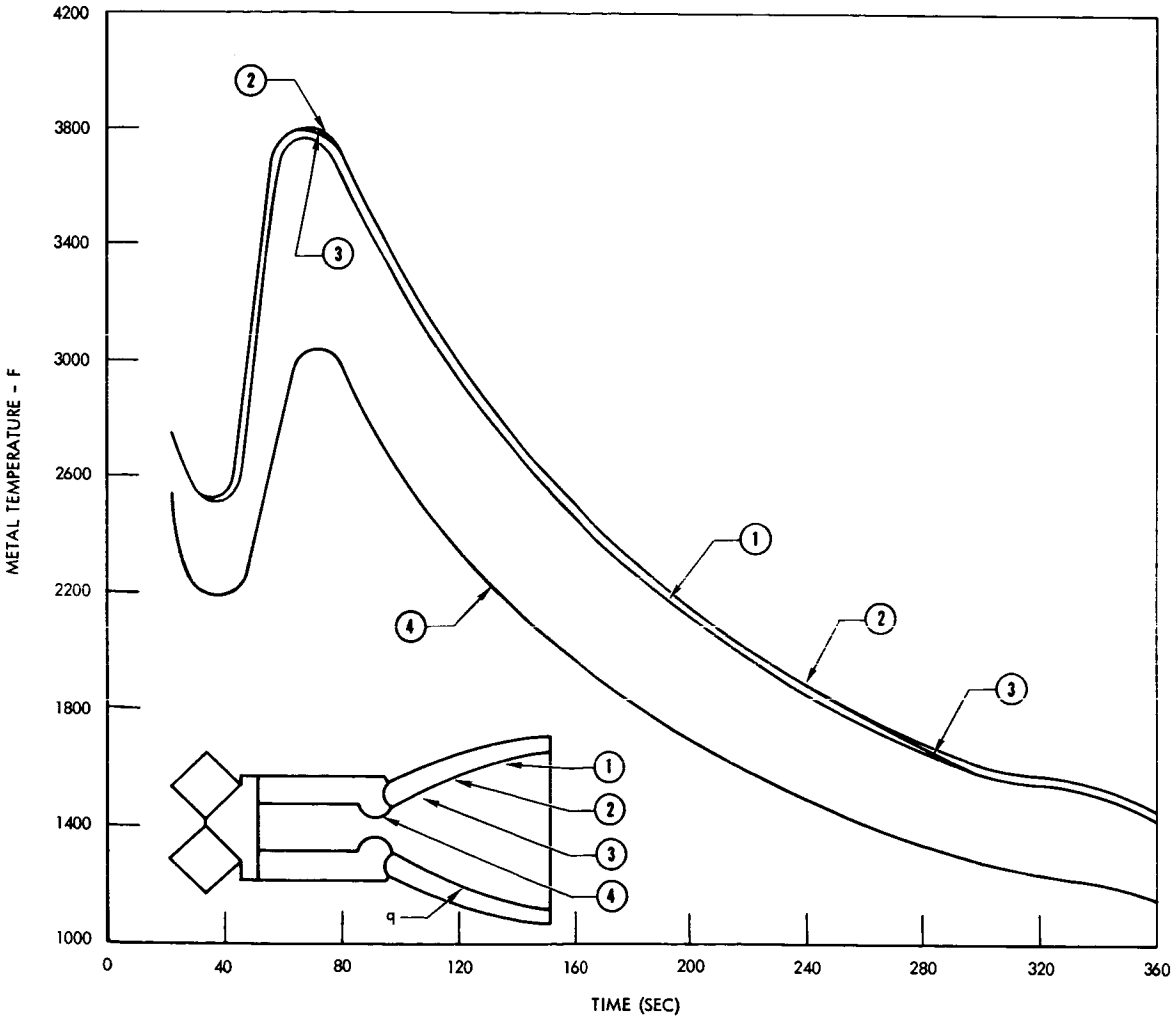


Figure 39. Semiradiation Cooled Engine (A) (Nozzle)

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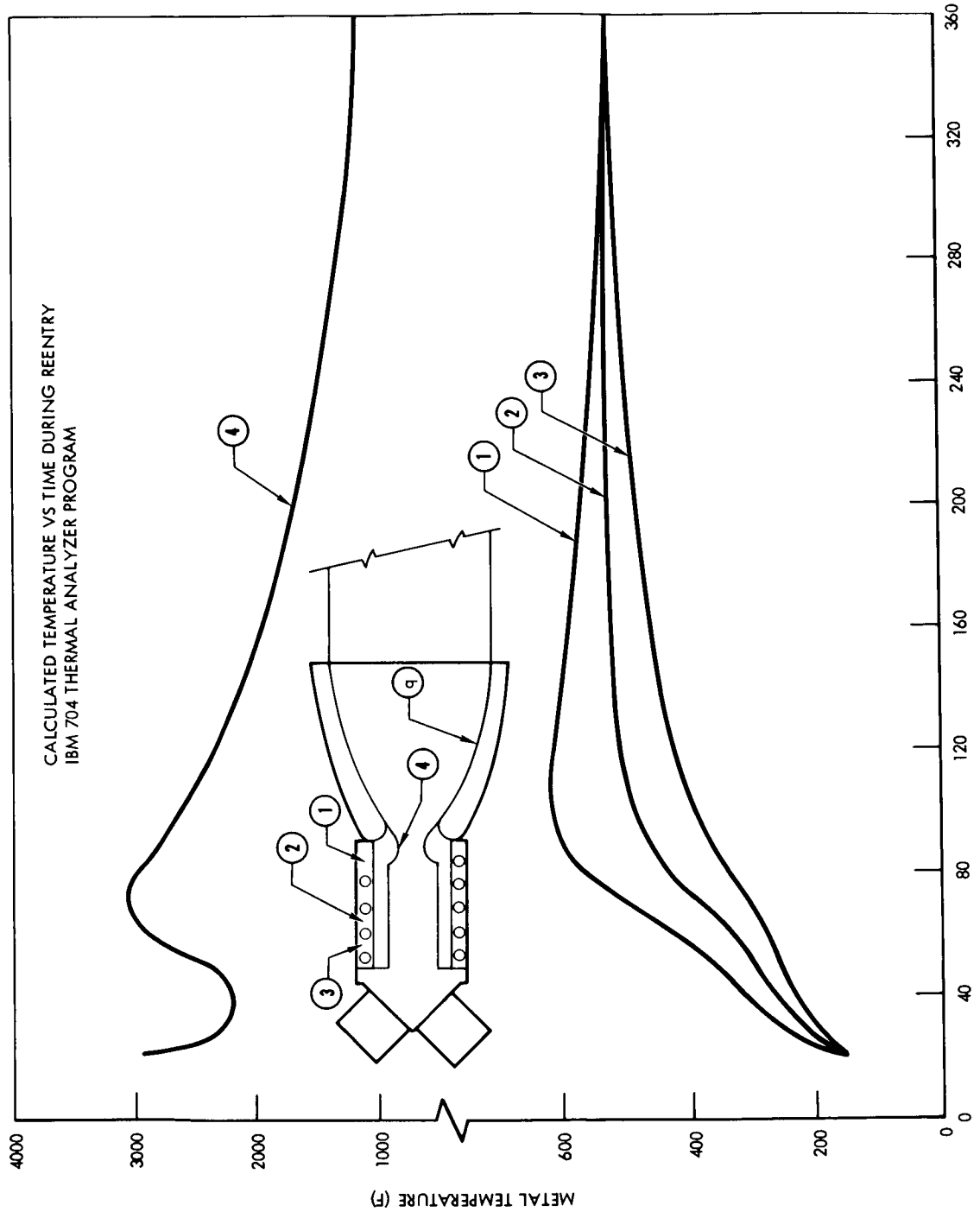


Figure 40. Semiradiation Cooled Engine (B) (Fuel)



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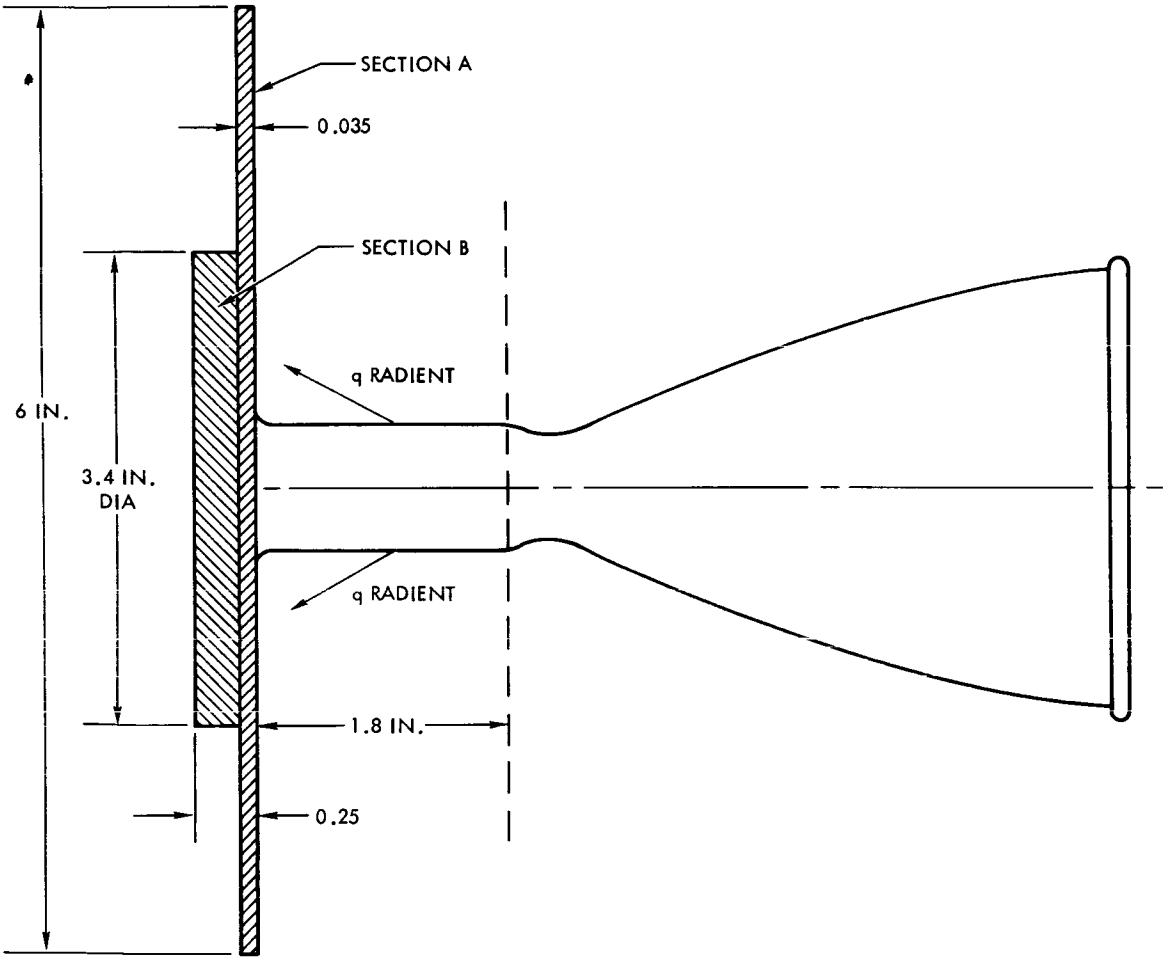


Figure 41. Service Module Reaction Control System Engine and Mounting Structure

The analysis also assumed a maximum service module RCS engine firing duration of 50 seconds (midcourse correction and/or emergency docking). With this firing time, the combustion chamber section of the engine (first 1.8 inches) reaches a temperature of 2900 F and radiates to the structure as shown in Figure 41.

Results of the analysis are presented in Table 11. They indicate that no problem will exist if the structure emissivity is less than 0.4, probably because this structural material will probably be aluminum. The emissivities of aluminum in various conditions (oxidized to highly polished) range from 0.19 to 0.039.

Table 11. Results of Analysis

| Structure Emissivity | Total Heat Transferred (50 Sec Firing) (Btu) | Heat Sink 1 (F) | Heat Sink 2 (F) |
|---|---|---|---|
| 0.72 | 13.60 | 970 | 179 |
| 0.60 | 11.40 | 815 | 151 |
| 0.50 | 9.60 | 675 | 126 |
| 0.40 | 7.53 | 547 | 99 |
| 0.30 | 5.46 | 390 | 72 |
| 0.20 | 4.80 | 343 | 63 |
| 0.10 | 2.50 | 178 | 33 |
| 0.05 | 1.25 | 89 | 16 |

An investigation was conducted relative to the RCS engine material (molybdenum with a molybdenum disilicide coating) for the service module. A literature survey was also made to obtain the latest available information on the use of these materials under Apollo environments. This survey showed several areas of potential concern relative to the use of molybdenum with a disilicide coating. Further investigation and tests will be conducted to determine the severity of these problems.

An analysis that considers the possibility of a buried service module RCS radiation-cooled thrust chamber was completed. This analysis indicates that such an engine installation would not be satisfactory for thrust chamber firing durations greater than 8 seconds. If an 8-second firing were made, considerable cool-down time would be required before another firing of similar duration could be made. This disadvantage, in addition to the possibility of a requirement for 50 seconds of firing during emergency docking, appears to eliminate the use of a buried engine installation.

The pulse operating characteristics of the RCS engines were analyzed. Specific impulse as a function of engine pulse width, engine thrust versus time characteristics, and total impulse as a function of engine on-off signal width were determined.

Rocket Plumes

A preliminary test plan covering the AEDC program was completed. A second experimental plume program to obtain exhaust plume impingement characteristics was initiated. The latter program will provide instrumentation and engine operating data that will be available for use in the AEDC tests. Plume heating rates will also be obtained.

Launch Escape Motor

A transient, one-dimensional, heat transfer analysis is in progress to determine temperature gradients and the time required to reach quasi-steady-state conditions through the launch escape motor grain.

Factors affecting the launch escape motor thrust vector alignment are being investigated. Calculations showed that the thrust vector was very sensitive to machining errors, nozzle erosion, or changes in the motor thrust coefficient.

A brief study was completed to determine the problem areas associated with increasing the length of the launch escape motor nozzle while keeping the nozzle area ratio constant. Problem areas associated with subsonic and supersonic blast tubes were also investigated.

A study is being made of the latest LES configuration to determine the rocket motor exhaust plume shapes and properties at various points in the trajectory. Results will be used to determine the shape of the upper portion of the tower, to establish the amount and location of ablative material on the tower, and to determine the dynamics and stability of the launch escape vehicle along the possible trajectories.

Service Module/S-IV Stage Separation

After the LES is jettisoned (at about 250,000 feet), the only way to abort the mission safely is through the use of the service module main engine. This separation technique, where the main engine pulls the Apollo vehicle away from the S-IV booster, has been called "fire-in-the-hole" separation. The minimum separation distance between nozzle and instrument wafer would be about 2 feet; the minimum blowout panel area would be about 130 square feet. These figures are based on the assumption that flow separation occurs when interstage pressure is three times the nozzle exit plane pressure. (See Figure 42).

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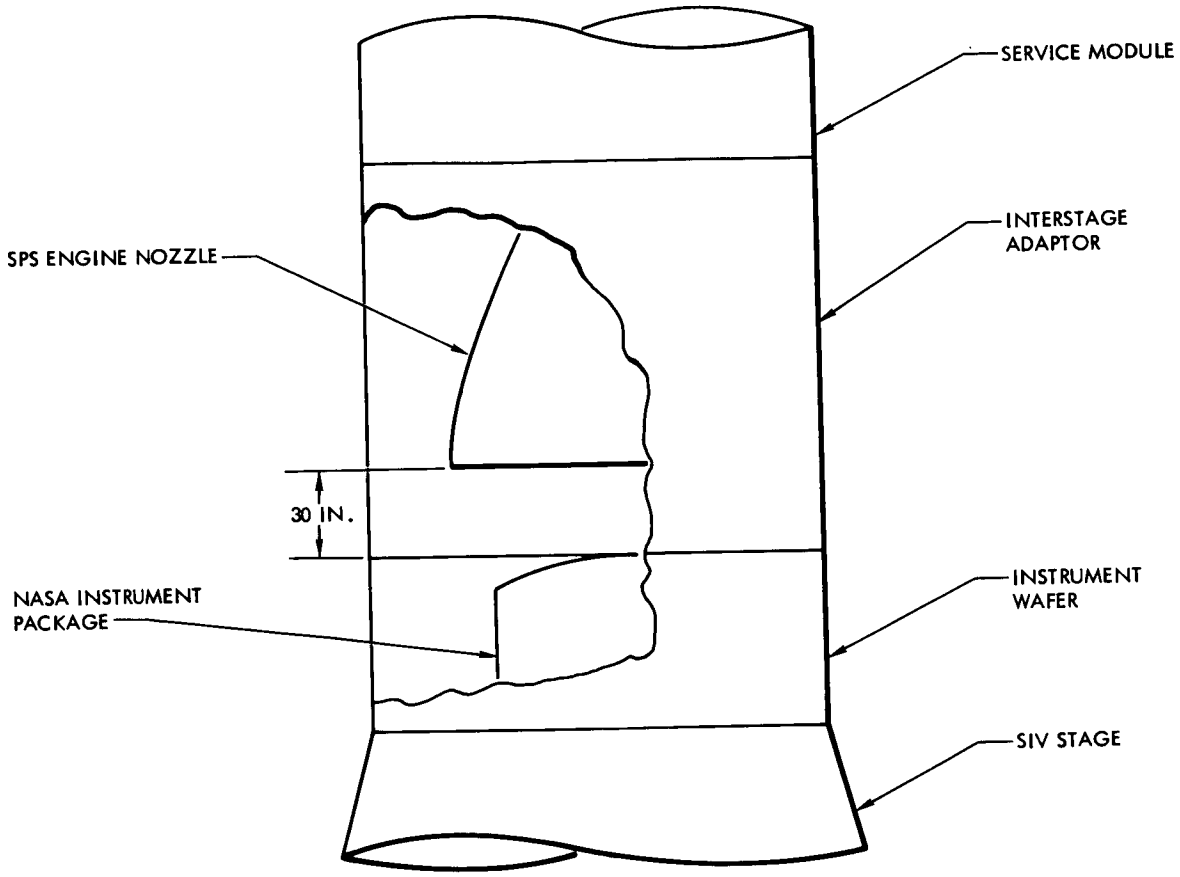


Figure 42. Service Module - S-IV Interstage Configuration

In the present design of the Apollo S-IV adapter, the NASA instrument package is located 30 inches downstream from the service module main engine (Figure 42). In order to show the shock wave position resulting from the exhaust gases impinging on this package (as a function of interstage compartment openings), a series of two-dimensional water table tests was performed.

Figure 43A illustrates a reasonably good interstage configuration. It shows the shock wave outside the engine nozzle and indicates that the instrument package is not too close to the nozzle. The blow-out panel size and location (below nozzle exit plane) accommodate the exhaust flow.

Figure 43B shows the same interstage configuration as Figure 43A except that the exit areas of the blow-out panels are partly above the nozzle exit plane. In Figure 43A the panels are located in the adapter only; in Figure 43B, the panels were located in the service module/S-IV interstage adapter and in the instrument wafer. This test illustrates the undesirable effect of the shock wave standing in the nozzle.

Figure 44A shows a configuration similar to the previous two tests except that the blow-out panel area is all in the adapter and the interstage is lengthened. Satisfactory results are shown, since the shock wave is located outside the nozzle.

Figure 44B shows the same interstage configuration as in the previous test except the blowout panels are located entirely in the instrument package. The shock wave is again standing on the nozzle.

These figures and the entire series of water table tests illustrate the critical importance of proper blowout panel location and size when fire-in-the-hole staging techniques are used. They also show that the proper location of the panel area is dependent on the shape of the shock wave created by the impinged target. The blowout panel area also seems most effective when it is located just at or below the shock wave.

A comparison of Figures 43 and 44 shows that the blow-out panels can be entirely located in the adapter if the adapter length is increased to allow for changes in the shock shape and location above the target. An extensive development program would be required to determine the effective blowout panel location and area while minimizing vehicle weight and height.

Alternate modes of stage separation are presently being investigated. These techniques include the use of posigrade rockets, retrograde rockets, and the service module RCS. Posigrade rockets appear to offer significant advantages as a means of accomplishing stage separation.

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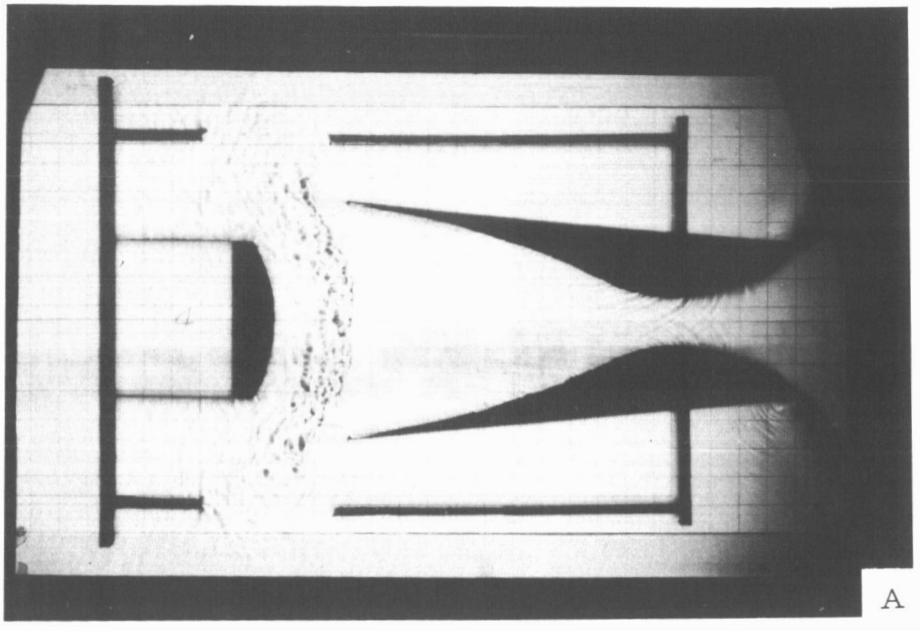
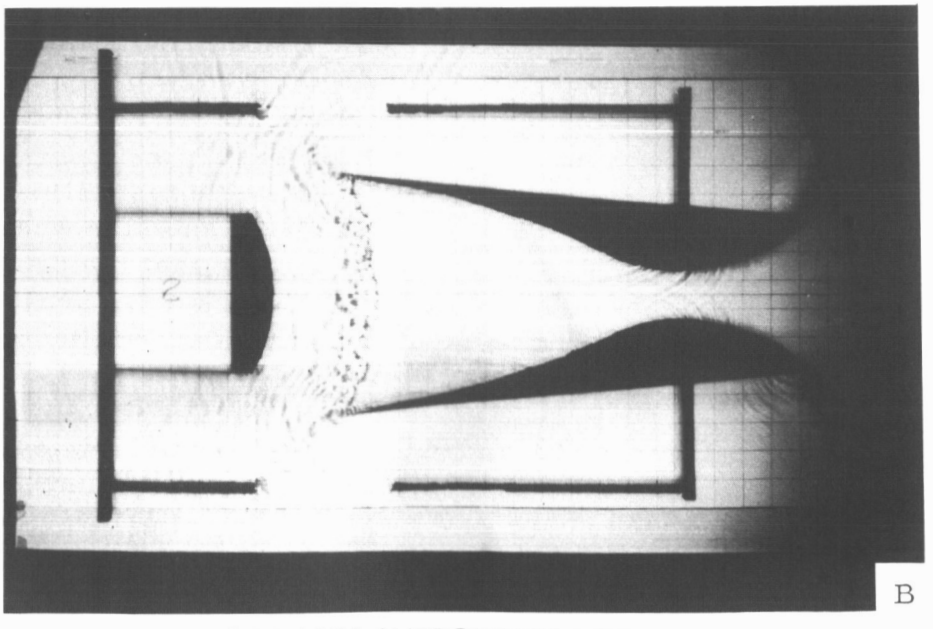



SM/S-IV INTERSTAGE SHOWING EFFECTIVE PORT AREA AND LOCATION

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PORT AREA IMPROPERLY LOCATED SHOCK WAVE IS INSIDE NOZZLE

Figure 43. Water Table Test



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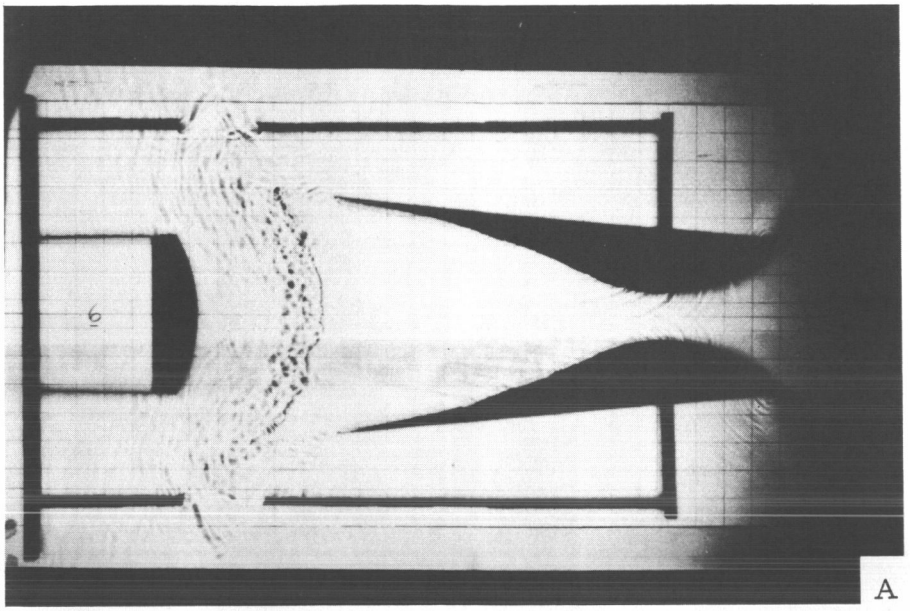
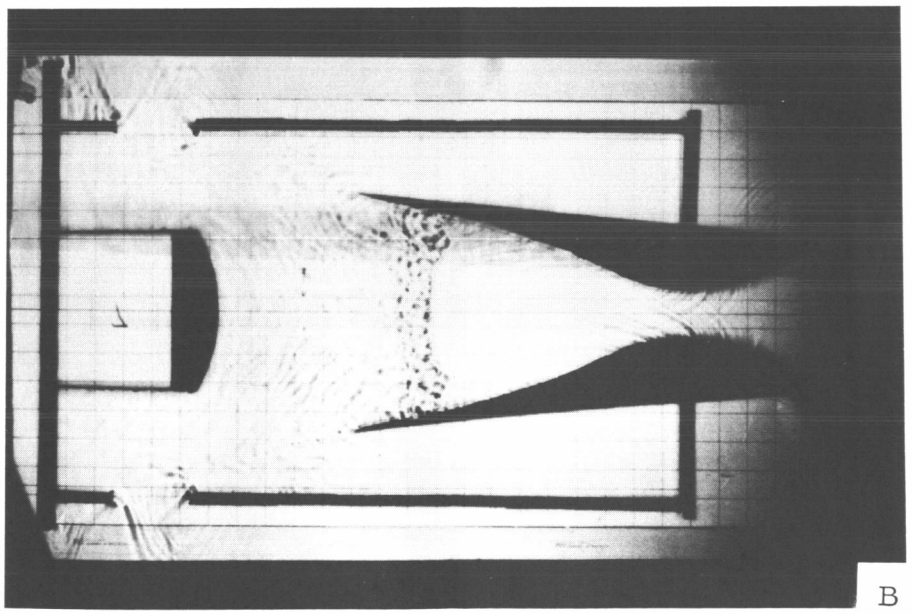


A

SM/S-IV INTERSTAGE SHOWING EFFECTIVE
PORT AREA AND LOCATION



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B

PORT AREA IMPROPERLY LOCATED
SHOCK WAVE INSIDE NOZZLE

Figure 44. Water Table Test With Blow-Out Panel Position Changed



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Service Propulsion System (SPS)

The SPS optimization studies and additional studies directed toward an optimum engine design for the lunar orbital rendezvous mission were continued.

Results of the optimization study are summarized in Figure 45. These results show how the the various engine parameters affect the spacecraft weight within the physical configuration limits of the service module and interstage adapter. As a result of this study, the engine nozzle expansion ratio was increased from 40:1 to 60:1 without changing the basic thrust chamber configuration. This nozzle change results in a slight increase in design thrust from 21,500 pounds to approximately 21,800 pounds. With a subsequent increase in the required service module propellant capacity to 45,000 pounds, a preliminary projection of the optimization study indicated that approximately 100 pounds of spacecraft weight would be eliminated by using the 60:1 nozzle.

A study was completed on the engine propellant line sizes required to maintain a constant engine mixture ratio even if one set of the propellant valves fails. An analysis of the initial design indicate that a 1.93 mixture ration would occur when one set of valves fails. This study also indicates that a constant 2.0 mixture ratio could be obtained (in both normal and failure-operating conditions) by reducing the inner diameter of the engine fuel valve to 1.5 inches.

An optimization study of the service module engine propellant line sizes (required by throat-gimbaling considerations) was conducted as a function of line pressure drop and propellant system dead weight. This study gave consideration to the weights of the propellant tanks, propellant lines, insulation on the lines, and the trapped propellant in the lines. Results of the study supported the recommendation that a 2-inch fuel line and a 3-inch oxidizer line be used.

PROPELLANT SYSTEMS

Service Module Main Engine - Pressurization System

The size of the helium bottle required for one continuous period of operation until propellant depletion can be reduced by adding to the pressurant. The ullage pressure increase that occurs during the coast period can be reduced by the addition of heat to the pressurant.

In the helium pressurization system weight optimization study, the overall system weight was based on one continuous single firing period, such as may be required for an abort condition. The advantages, disadvantages, and characteristics of the systems are presented in Table 12.

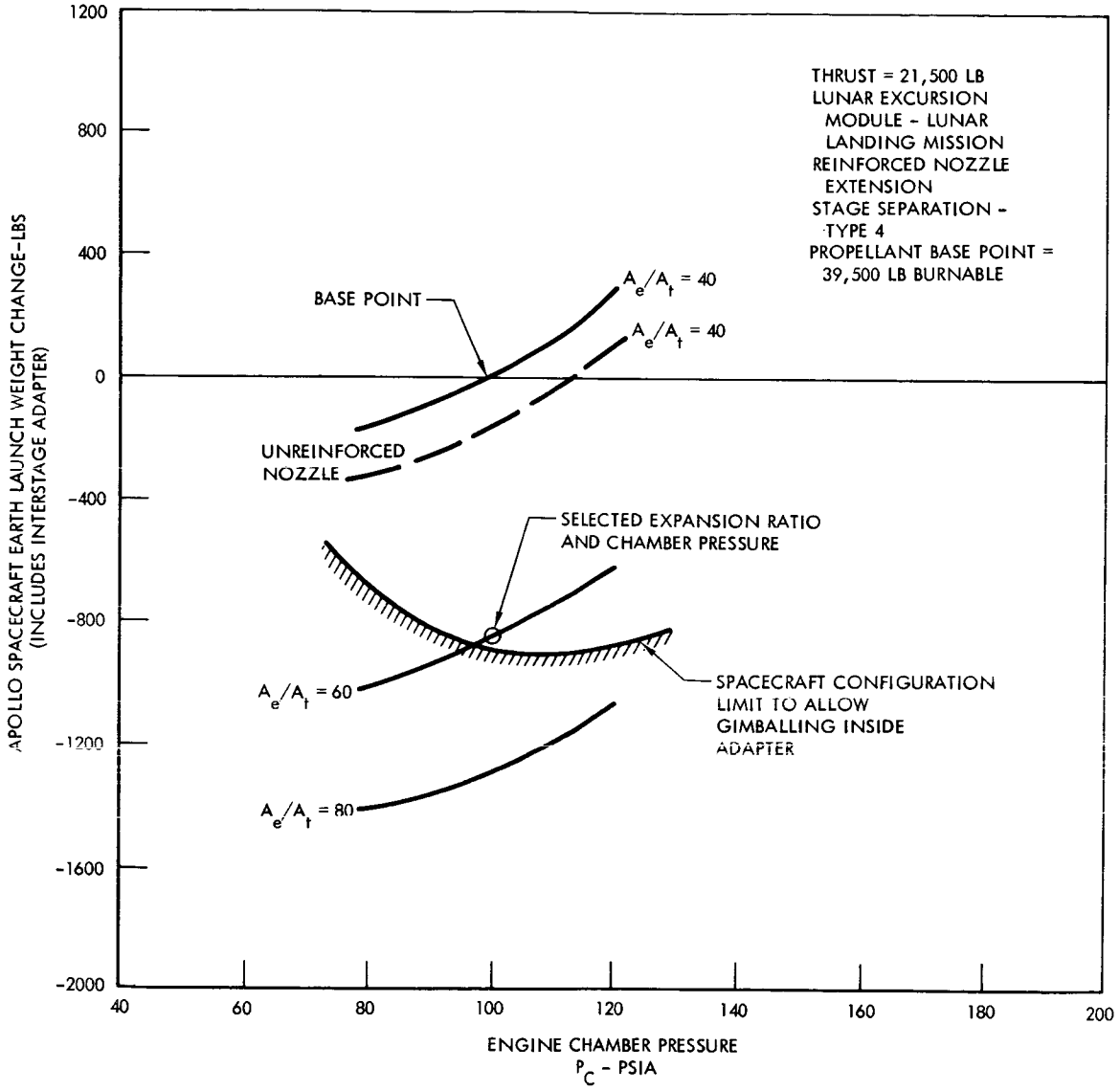


Figure 45. Apollo Spacecraft Earth Launch Weight Change - Lb. (Includes Interstage Adapter)

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Table 12. Systems Considered for Service Module SPS Pressurization

| System | Advantages | Disadvantages |
|---|---|---|
| Ambient Helium Storage No Heat Exchanger | Simplest Design<br>Short tube length<br>Fast response on demand<br>Minimum development risk | High system weight<br>Greatest ullage pressure excursions during coast periods |
| Ambient Helium storage, Helium bubbling through both propellants | Good heat exchange between Helium and propellants<br>Ullage in the first set of tanks saturated before going to zero g<br>Low pressure excursions during zero g<br>Performance can be greatly improved by bubbling into both first and second tank | Helium is at a somewhat higher than ullage pressure on entering the tanks; it may oversaturate propellants and come out of solution in the engine lines<br>Helium heating is hard to provide for the duration<br>Uncertainties connected with a technique that was never used in similar circumstances<br>Bubble cap or diffuser design needs development and test evaluation<br>Subsurface helium effect on liquid level and liquid level sensors |
| Ambient Helium storage | Simple heat exchanger design<br>Helium heating provided during entire flight<br>Helium temperature and heat exchanger performance fairly predictable<br>Less development risk than bubbling system | About 20-25 ft additional low pressure seamless tube length<br>Slight possibility of solid fuel deposit on exchanger coil |



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Table 12. Systems Considered for Service Module SPS Pressurization (Cont'd)

| System | Advantages | Disadvantages |
|---|---|---|
| Cryogenic Helium storage, heat obtained from engine | Minimum system weight and volume<br>Similar systems are already operational<br>No ullage pressure increase during coast periods | Some complexity in the system.<br>Some testing needed on insulation and heat exchanger<br>Large regulator operating temperature range if only low pressure helium is heated<br>Possible engine development problem |

The tank ullage pressure histories were calculated for a simplified lunar excursion mission. The pressure excursions and elapsed times to reach the steady pressure condition after engine start are given in Figures 46, 47, 48, and 49. Figure 50 presents data for the configuration including a fuel to high pressure heat exchanger.

The ullage pressure rise after translunar midcourse correction is based on a single firing and in initial ullage of 1 cubic foot. If the midcourse correction consisted of several firing periods, the subsequent ullage pressure rise would be less than shown in Figure 46, 48, and 49.

The analysis data for the propellant pressurization system using helium bubbling heat exchange are presented in Figure 50. The pressures and temperatures of the helium in the bottle and ullage, in regard to the operating time, are plotted for the case of continuous engine operation during a simulated abort mission. At the present time, a fuel to low-pressure helium heat exchanger is recommended. Studies of other heat exchanger systems will continue.

Propellant Feed Lines

The propellant system weight was determined for various feed line sizes and for a single-propellant utilization valve configuration.

Results indicate that the choice of a 2-inch inner diameter fuel line and a 3-inch inner diameter oxidizer line will result in a minimum propellant system weight.

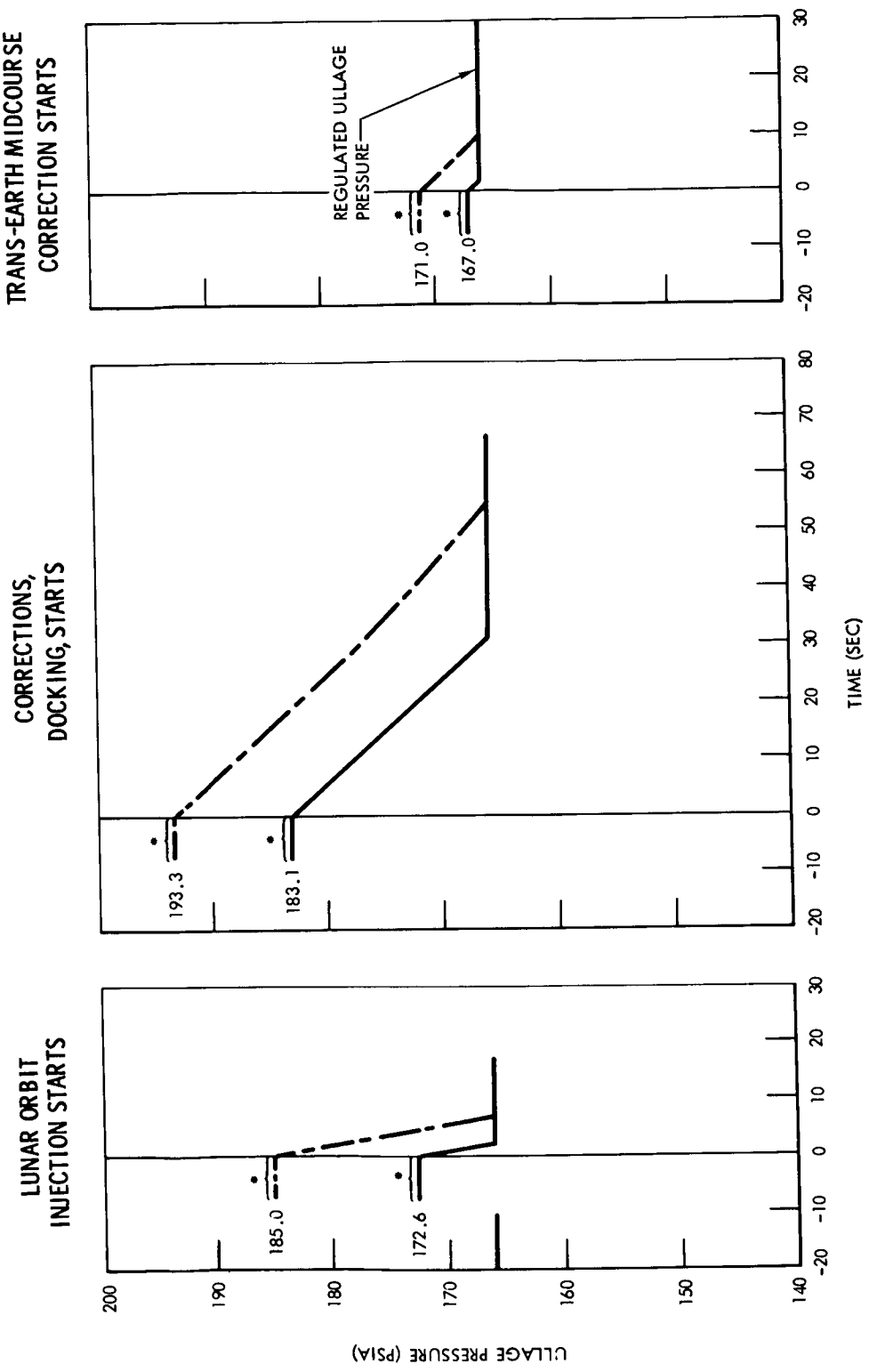


Figure 46. Helium Pressurization System With No Heat Exchanger

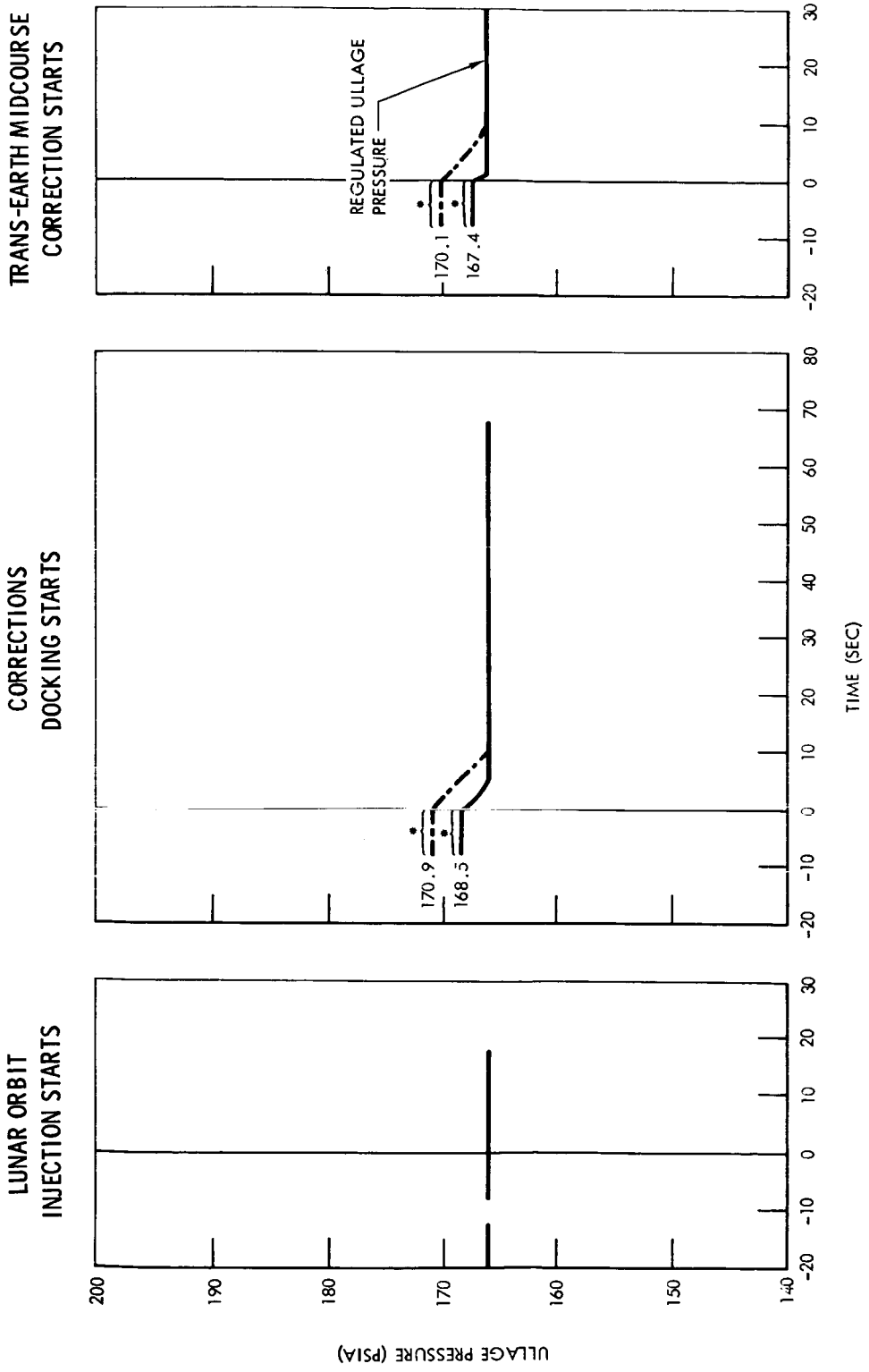


Figure 47. Helium Pressurization System With Bubbling Heat Exchanger

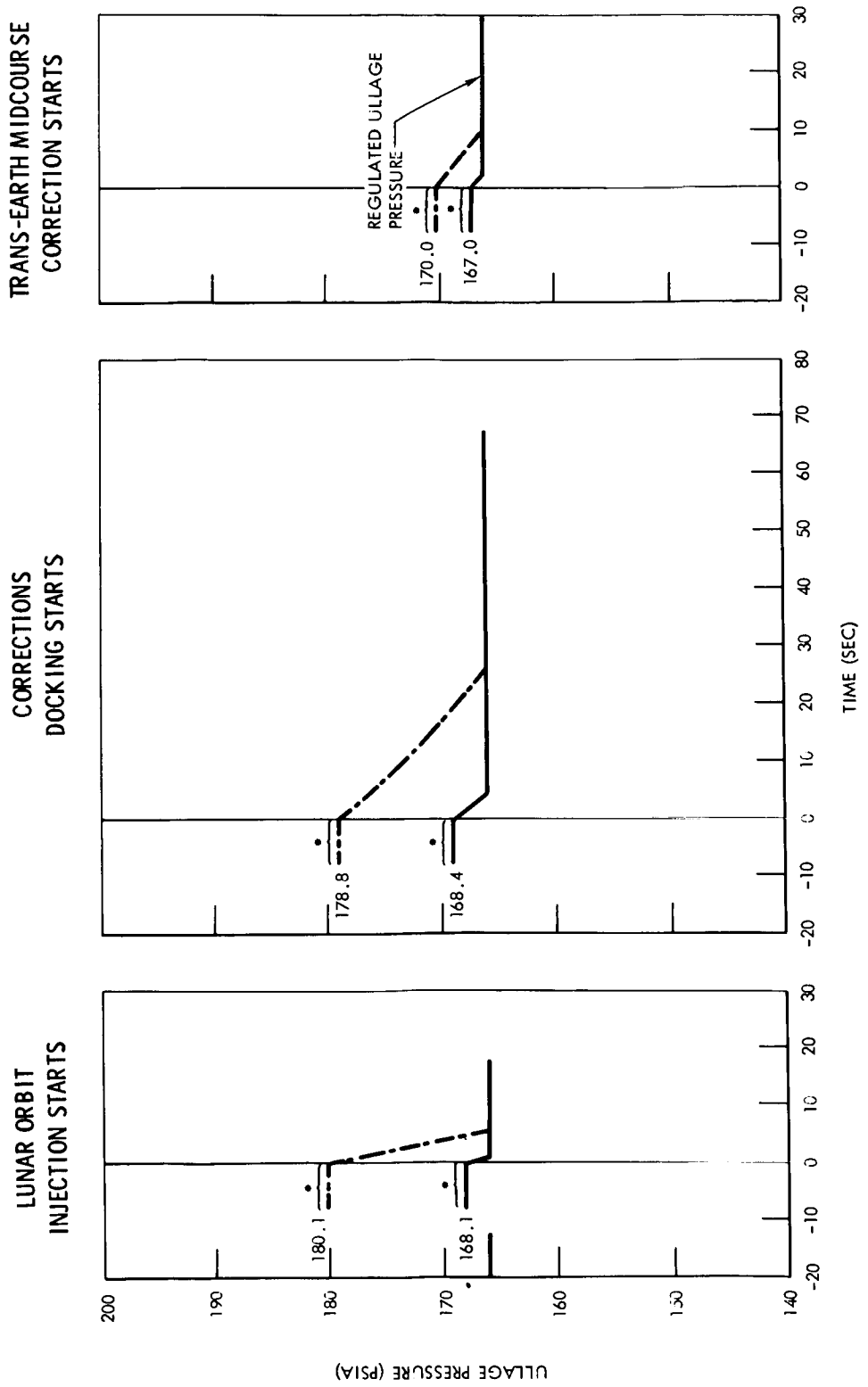


Figure 48. Helium Pressurization System With Low Pressure Heat Exchanger

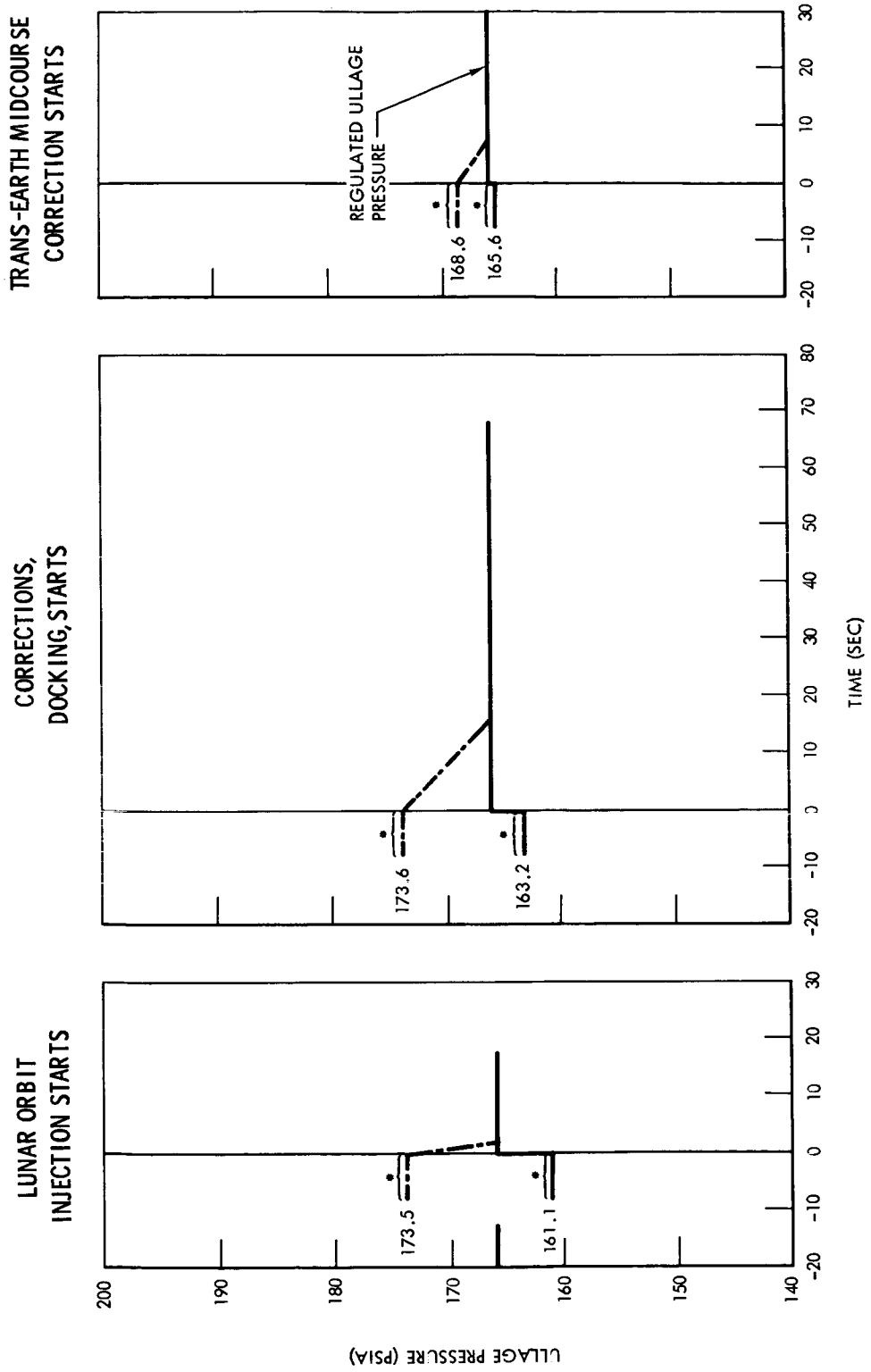


Figure 49. Helium Pressurization System With High Pressure Heat Exchanger

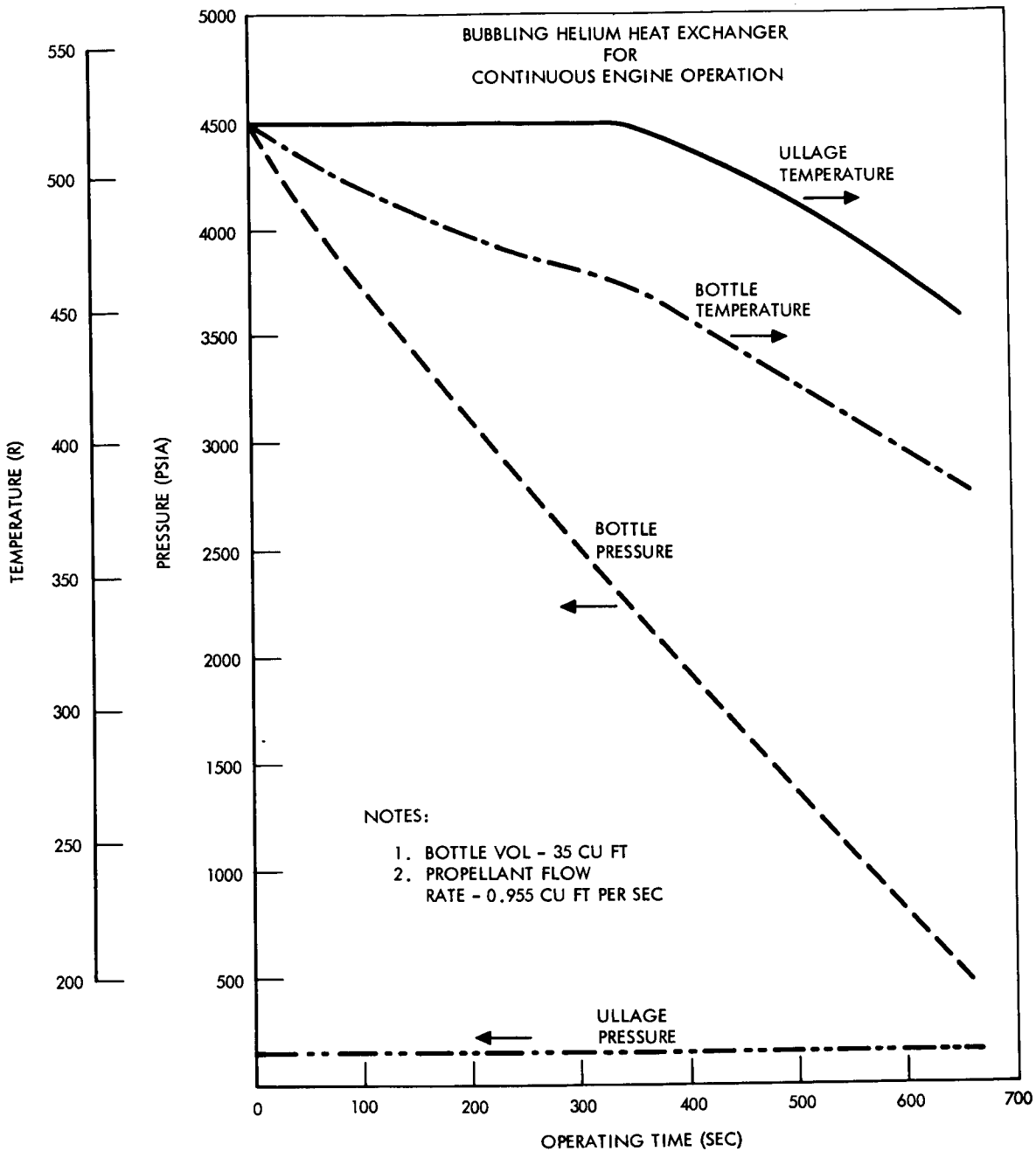


Figure 50. Pressure and Temperature History for SPS Helium Pressurization System

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## Command Module RCS

A study was completed that consisted of trade-off weight savings in propellant transfer lines versus weight savings in the helium pressurization system and in the propellant storage tanks for various sizes of the propellant transfer lines.

A preliminary analysis was completed to size the helium reservoirs and transfer lines of each of the command module RCS helium pressurization systems. Results of this analysis show that the helium reservoirs should be about 9.5 inches in inner diameter.

## Service Module RCS

An analysis of the service module RCS was made to determine the required line sizes. Lines of 0.2-inch inner diameter or greater do not present any significant line losses under normal operating conditions. The relief valve performance under abnormal operating conditions is under study.

The pressure surge (water hammer effect) in the service module RCS was determined as a function of line inside diameter and the number of motor firings. An analysis was performed on a simplified system and gives values higher than those actually existing. For the case of three engines firing and a 0.375-inch inner diameter line, the transient pressure rise is 500 psi maximum.

An analysis was made of the effect of variations in temperature between the oxidizer and fuel on the mixture ratio in the service module RCS engines. The results of this analysis are shown in Figure 51. Figure 51 illustrates the resulting oxidizer-fuel mixture and respective flow rates for a given oxidizer temperature and fuel temperature. When a 20 F temperature difference prevails between the oxidizer and the fuel, it was found that the mixture ratio would vary less than two percent under the most extreme conditions. There will be about one percent shift in mixture ratio at higher temperatures even if no temperature difference existed.

## Temperature Control Coatings

Twenty-six space radiator surface coatings were obtained for the orbital solar observatory (OSO) test. The samples obtained are being measured for solar absorptivity and ultra-violet emissivity. Those samples that meet the Apollo radiator thermal property requirements will then be subjected to a simulated space environment of ultra-violet light under hard vacuum then remeasured to determine the extent of degradation. The most promising light specimens will be selected for testing on OSO flight.

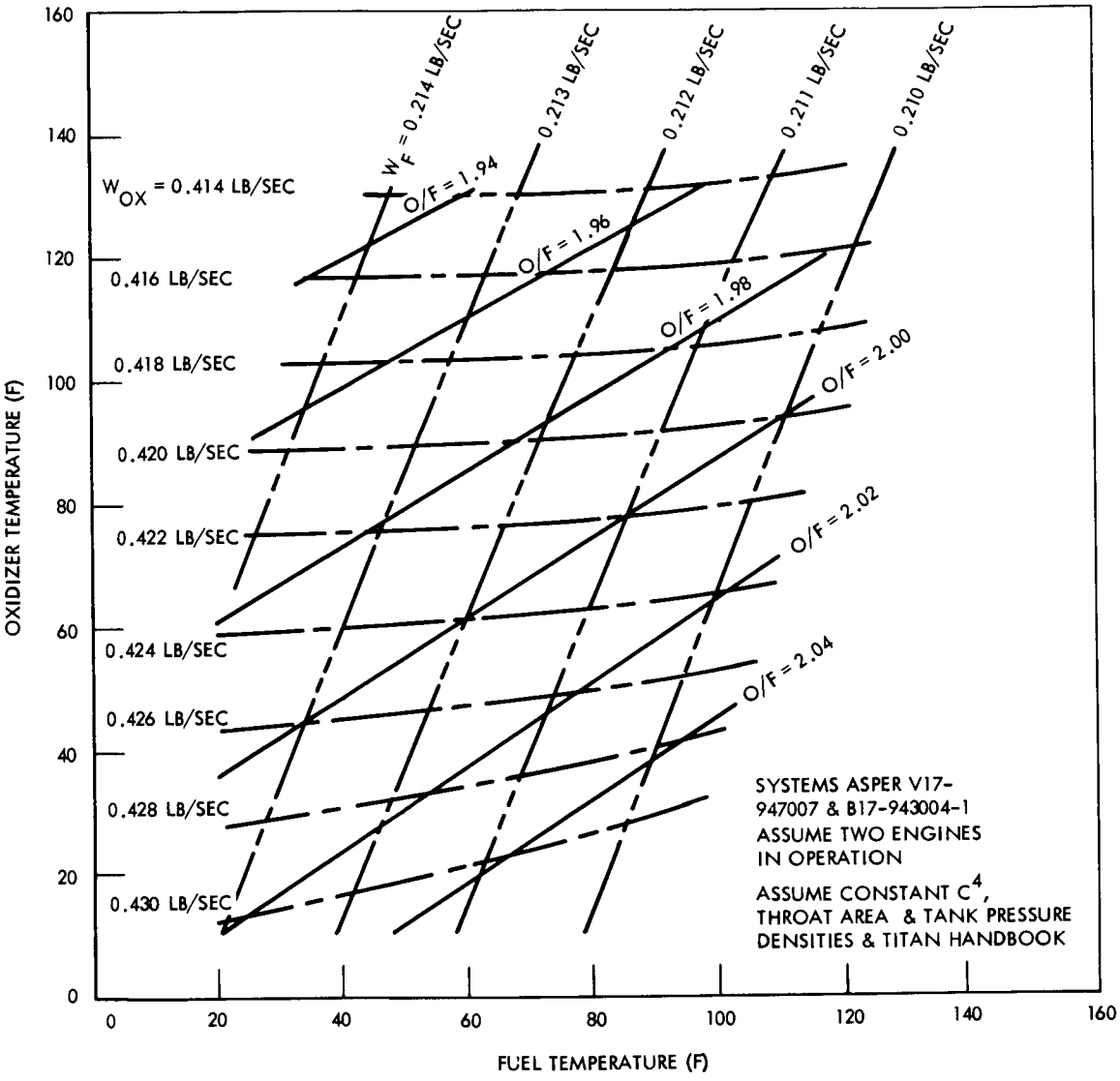


Figure 51. Service Module - Reaction Control System, Mixture Ratio Variations

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The first information available shows an absorptivity of the various samples varying from 0.1 to 0.2, all being within the allowable range for the Apollo radiators. The emissivity data will depend upon integration of the spectral curves.

# INTEGRATION AND SUBSYSTEM ANALYSIS

## ACOUSTIC TESTS AND LANDING DYNAMICS

A sonic test program was begun on a typical heat shield panel to determine the vibration response of the structure to acoustic excitation. These data will be used to specify vibration requirements for tests of ablative material bonding to substructure.

Equations were written and a digital program is being prepared for the the analysis of command module earth landing. A system being considered includes a heat shield flexibly attached to a command module structure that supports an impact-attenuating couch.

## FLUID DYNAMICS AND PANEL RESPONSE

Studies were initiated and calculations were made to describe the behavior of liquids in low and zero-gravity fields. Fuel sloshing and utilization from service module tanks were examined.

A study was initiated on the response of spacecraft structural panels to vibration excitation. Experimental results were obtained from a series of laboratory tests on various panels with and without weight attached.

## LUBRICATION SYSTEMS

Currently available lubricants and lubrication systems for space applications may not be adequate for manned space vehicles. Investigation of new lubricants or lubrication systems, particularly in the conceptual stage, was initiated. One such system that may be of value, when used with magnetic materials, is a system attached and held by magnetic force to the surface requiring lubrication. Such a system will eliminate the adhesive properties required of some systems.

## SILICONE RUBBER COMPOUNDS

The cryogenic properties of silicone rubber compounds, needed as part of the mechanical attachment between the inner and outer command module shells, were determined. Because data were available on the very low temperature characteristics of silicone rubber compounds, the strength and ductility of two silicone rubbers were determined at temperatures ranging from 70 to -280 F. Although low-temperature elongation was found to be as

low as approximately one percent at -280 F and tensile strength increased in proportion to ductility decrease, investigation showed that there was no danger of silicone rubber shattering at very low temperatures.

## REACTION CONTROL NOZZLE MATERIAL AND PROTECTIVE COATING STUDIES

A study was conducted to determine the probable characteristics of refractory reaction-control nozzle materials and applicable protective coatings. Disilicide-coated molybdenum alloy nozzles were tentatively selected. Studies revealed that the coating will probably leave the nozzle surface under service environment conditions and be redeposited on temperature-control surfaces downstream from the nozzles. This condition cannot be tolerated. Disilicide coatings are brittle and have an absolute maximum service temperature of about 3000 F. Meteoroid impingement could ruin a disilicide coating of 0.002-inch thickness. The proposed service temperature of the nozzle is about 2900 F; this temperature appears to be too high for safety when compared with the 3000 F operating maximum. In addition, the emissivity of the disilicide coating is too low for optimum radiation-cooled nozzles.

## STRESSKIN HONEYCOMB SANDWICH PANELS

Several all-welded Stresskin René 41 honeycomb sandwich panels were made to determine the ability of this material to meet the requirements of the Apollo outer structural shell. René 41 is one of the strongest and most temperature-resistant superalloys. A sandwich panel must be of a predetermined configuration, including mild compound contours, in order to serve as an Apollo afterbody structural shell component.

Because Stresskin is reported to be formable after being fabricated into flat panel form, a typical die was made, about which the flat René 41 Stresskin sandwich could be contoured.

Attachments were made by bonding fixtures to the honeycomb panel edges, which could be gripped by the stretch press jaws. The panel was set in place and gripped, and stretch forming was begun. The bond finally failed, but not before the forming was well under way. Before the bond failure occurred, the inner face elongated 6 percent and the outer panel 7 percent. The compound contour was also partially formed. No tearing or wrinkling was encountered in either face of the sandwich.

## THERMAL SHOCK TESTS

The honeycomb sandwich thermal shock test was devised to act as a common denominator in the comparative evaluation of both brazed and

all-welded metal honeycomb sandwiches. The test constitutes the sudden exposure of a specific specimen configuration and size to a predetermined heating rate and load. The specimen should theoretically withstand this exposure without failure. The heating rate and load requirements vary in proportion to the sandwich material thickness and composition and the braze alloy properties (if the sandwich being tested is brazed).

The tests have shown that one brazed HS-25 and one brazed Rene' 41 sandwich have successfully withstood thermal shock tests.

Sandwich specimens that failed thermal shock tests include one brazed HS-25 sandwich, one brazed PH 15-7Mo sandwich, and one all-welded PH 15-7Mo Stresskin sandwich.

## APOLLO WINDOWS

The Apollo window material requirements, optical requirements, and processing requirements were established. The optical requirements, material composition, configuration thickness, acid etching of the edges, heat treatment, identification, surface finish for spacecraft windows, and special ground surface of test aluminosilicate windows were established. Tentative costs and delivery schedules were determined.

Studies of alternate sealing designs were initiated. Two panes will be required for the windows in the pressurized cabin. The space between the panes must either be evacuated or filled with an inert gas. Exposure to ionizing space radiation of sufficient intensity may cause all inert gas to glow. The openings in the outer shell may be fitted with doors (controlled from the cabin) unless a transparent material capable of withstanding such environmental conditions as meteoroids and entry heat can be found.

## LANDING DYNAMICS

An analysis of earth-landing impact and stability was completed, using a mathematical model having two masses and 3 degrees of freedom. Parameter variations included vertical and horizontal velocities, pitch attitude, ground slope, and coefficient of friction. The most significant finding was that a 5-degree pitch attitude resulted in better all-around landing performance than the original concept of 15 degrees nose down. Other results obtained included the possible generation of high horizontal accelerations during landing with moderate to high horizontal velocities.

DESIGN DATA

Data for titanium alloy 6A1-4V was issued for inclusion in the structures manual. Both the annealed and STA conditions were covered from room temperature to 900 F.

Preliminary design data for the following alloys in sheet form were issued:

Aluminum alloy 2014-T6 (room temperature to -423 F)

Aluminum alloy 6061-T6 (room temperature to -400 F)

Magnesium alloy HM 21A-T81 (room temperature to 600 F)

Steel PH 15-7Mo (room temperature to 900 F)

Tool-steel type H11 (room temperature to 900 F)

Nickel-base alloy René 41 (room temperature to 2000 F)

Cobalt-base alloy L605 (Haynes 25) (room temperature to 2000 F)

Titanium alloy 6A1-4V (-100 to -423 F)

DYNAMIC RESPONSE

Studies were completed to determine flotation stability envelopes for command modules of several different weights. The results obtained show the flotation attitude of the vehicle for any center-of-gravity position. The command module has two distinct and stable flotation attitudes for a rather wide range of center-of-gravity locations. This was later verified in an actual flotation test of boilerplate 25.

LES MODES AND FREQUENCIES

Natural modes and frequencies were calculated for several versions of the LES motors and tower. Both cantilever cases and booster-command module-LES combinations were evaluated. Major concern over the rather low frequencies of the various cantilever systems no longer exists since an accelerometer sensing system was adopted (rather than the q-ball device for the C-1 booster).

## SHOCK, VIBRATION, AND ACOUSTICS

A review of the equipment design and mounting provisions was initiated. This was based on present environmental predictions for various areas of the spacecraft. All effort was examined to ensure that response to expected shock, vibration, and acoustic excitation would not be excessive or detrimental.

## TEST PLANS

The following Apollo test requirement (ATR) test plans were prepared:

Vibration and acoustic tests of typical command module panels

Vibration and acoustic tests of typical service module panels

Vibration and acoustic tests of typical adapter panels

Spacecraft environmental vibration test

Spacecraft modal and vibration transmissibility test

Spacecraft environmental acoustic test

These programs are designed to provide experimental information on the ability of the spacecraft structure and equipment to withstand dynamic environments.

An extensive measurement program was developed, during static firing operations and on boilerplate and spacecraft flight to provide data for the confirmation or modification of the anticipated shock, vibration, and acoustic environment.

## DYNAMIC TEST

The first part of an experimental drop test program was completed at NASA Langley Research Center using a 0.25-scale dynamic model. A total of 23 drops were made, into sand, with the impact attenuation strut system installed. Horizontal velocities were 0, 30, and 50 fps while vertical velocity was fixed at 30 fps. Attitude at impact was varied from -20 to +15 degrees in 5-degree increments. Loads were slightly lower than anticipated (20 g's at the center of gravity or less) and the over-all stability ranged from good to excellent. The next step in this program will be drop the model onto a concrete surface. After the conclusion of these tests, a series of water drops will be conducted.

## LOADS AND CRITERIA

Transient loads in the spacecraft immediately following release from the launch pad with a 99-percent wind were completed. The bending moment in the spacecraft and the tension tie loads between the command module and service module are larger than at any other point in flight with the possible exception of uncomputed first-stage cutoff.

Body loads on entire spacecraft were computed for service module lengths of 155, 140, 124, and 150 inches; adapter lengths of 135, 105, 110, 92, 160, and 250 inches; command module weights of 49,780, 50,800, 28,850, 56,500, 13,750, 29,680, 47,830, and 11,940 pounds; and adapter weights of 6800, 300, 610, 1220, 1320, 700, and 770 pounds. Loads were computed for C-1 and C-5 boost. The $q\alpha$ for C-1 was 5400 pounds per square foot-degree and for C-5 was 7320 and 7910 pounds per square foot-degree.

The loads analysis of the LES using escape motor thrusts 120,000, 135,000, and 155,000 pounds; kicker motor thrusts of 3400, 6000, and 8400 pounds; ballast weights of 375, 750, and 1500 pounds; command module weights of 8340, 8920, 9250, and 6000 pounds; and pitching velocities of 360, 250, and 120 degrees per second. The loads were computed for pad abort, maximum q abort, and vacuum abort.

Studies were completed that showed the change in thrust alignment as a function of angle of attack and dynamics pressure, escape rocket thrust and inclination, kicker rocket thrust, and tumbling velocity.

Command module pressure distributions have been completed for C-1 and C-5 boost and for aborts off the pad and at maximum q. During boost, the angle of attack was limited to 15 degrees and the dynamic pressure was compatible with the booster. During abort, the angles of attack ranged from 0 to 360 degrees and the dynamic pressure went as high as 900 psf.

Service module and adapter pressure distributions have been computed for the critical C-5 boost trajectory. The pressure is negative gage just aft of the command module-to-service module interface, increases sharply to small positive gage, and levels off further aft.

## COMMAND MODULE

Support for the heat shield honeycomb panels ATR program was completed, but a number of machine parts are still in work. This includes the frames for the windows, inner structure aft ring and strut pad fittings, and inner structure side wall welds.

The left- and right-hand side console panels of the crew compartment were defined. A revision of requirements to incorporate five windows instead of three will make the right-hand definition obsolete. Both sides are now identical.

Other structure definitions in work or completed include the crew compartment heat shield aft panels and maintenance doors, aft heat shield panel splices and trims, crew couch attenuation strut points, crew observation windows, shock strut points, and fittings.

Volumes of the equipment bays and compartments were computed.

The launch escape tower access well was revised, and the present definition is in work.

A computer program for the command module stability study was completed for the structures group. A technical report has been prepared outlining the techniques and loading procedures of the program.

## HEAT SHIELD AND SHELL ANALYSIS PROGRAM

The objective of this program is to develop analytical methods to determine the internal force resultants in shells of revolution subjected to nonuniform external forces and thermal gradients. These analytical methods will be valid for shells with variable stiffnesses in the meridial and circumferential direction and will include composite sandwich and skin-stringer construction. The analytical methods developed will be directly applicable to the shell structure used in the Apollo spacecraft.

The partial differential equations of equilibrium for a toroid, a sphere, a cone, and a cylinder have been derived including thermal effects and variable extensional and flexural stiffnesses. These equations were derived using small deflection theory and are valid for unsymmetrical loadings.

The partial differential equations of equilibrium were expanded into finite difference equations by assuming equal differences and by assuming that all functions and their derivatives are continuous. In addition, the equations that express the internal force resultants as a function of the deflections and deflection derivatives have been expanded into finite difference equations.

Methods of satisfying the boundary conditions that will be encountered in an Apollo-type shell structure have been devised. These boundary conditions would include shells with free edges and shells that join to other shells by various connection mechanisms. The equations of constraint at the boundaries have also been expanded into difference equations.

Methods of formulating the stiffness matrix of a shell using the finite difference equations have been investigated. These methods include different methods of incorporating boundary equations into the stiffness matrix and of satisfying the equations of equilibrium and compatibility between adjoining shells.

An IBM program for inverting an unsymmetrical band matrix by partitioning was compiled and checked out. This program is capable of inverting any band matrix in which the band width does not exceed 160 elements.

Several sections of the Apollo heat shield were prepared for IBM programming using the existing heat shield concept.

A structures technical report is being prepared to present the equations that have been derived to date and a general discussion of the use of these equations in the analysis of shell structures.

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# RELIABILITY

## SERVICE MODULE REACTION CONTROL SYSTEM

Reliability engineering has completed a detailed evaluation of four configurations of the service module reaction control system (RCS). The configurations investigated were (1) a dual system of two redundant propellant supply subsystems supplying four clusters of four engines each, (2) a triple system of four individual and independent propellant supply subsystems each of which supplies one cluster of six engines each, (3) a quad system of four individual and independent propellant supply subsystems each of which supplies one cluster of four engines each, and (4) a quad plus one spare system identical to the normal quad system with the addition of a complete propellant supply subsystem and engine cluster as an independent spare.

From the reliability view point, these systems are ranked in the following order:

1. Quad plus one spare
2. Triple system
3. Quad system
4. Dual system

The quad with spare and triple system meets the mission success and crew safety reliability requirements for conditions where three of the four clusters are required and where two of the four clusters are required. These analyses are based on the assumption that certain modifications to the original design will be made, including use of redundant diaphragms within the tank, use of certain redundant valves, and sufficient factors of safety in the engine structure to assure meeting the engine requirement.

## HIGH-ALTITUDE ABORT

A reliability evaluation was conducted on four proposed configurations for initiating high-altitude aborts in the event of an emergency. The results of this study are contained in Table 13.

Table 13. Configurations for Initiating High-Altitude Abort

| Configuration | Predicted Failure Rate (Failures/$10^6$ Hours) | Other Considerations | Order of Preference |
|---|---|---|---|
| Service module propulsion system and six posigrade rockets on service module | 110 | Self-contained in service module + redundancy | 1 |
| Command module reaction control system and retrorockets in S-IV stage | 50 | Not self-contained in service or command modules | 2 |
| Service module propulsion system | 230 | Required blowout panels and shaped charges to exhaust adapter hole | 3 |
| Command module reaction control system | 4000 | | 4 |

Quality Control Documentation Requirements

S&ID process control procedures submitted to NASA consisted of 29 quality control specifications and quality control calibration and Volumes 1 and 2 of the preventive maintenance manuals, which include inspection, measuring, and test equipment procedures.

Review of Subcontractor Documentation

Four subcontractor quality control plans were reviewed. Approvals have now been given to the quality control plans of Collins, Avco, AiResearch, and Minneapolis-Honeywell. Six subcontractor end-item test plans and 85 other types of approval documents have been reviewed for inclusion of quality control provisions. Ninety-one Type II progress and status reports were also reviewed for surveillance of subcontractor quality activities.

## Specifications

Twenty-three specifications were reviewed to ensure that applicable documents are included, that design requirements are adequately defined, that quality assurance provisions contain essential requirements for conducting a test program which will verify functional integrity of the article, and that supplier quality control system complies with requirements.

A procedure has been developed that delineates the responsibility of quality engineering for procurement specification review and provides for documentation of these reviews. A check list is provided in conjunction with this procedure to be used as a guide for verifying specific requirements and conditions.

Six specification control drawings for the procurement of off-the-shelf items were reviewed.

A quality control specification entitled "Quality Control Requirements for Machine Fusing Welding" was released. Quality control specifications covering radiographic inspection and certification of manual fusion welders are being developed.

## Identification and Traceability

The S&ID identification and traceability system concept has been established and documented. A letter sent to NASA explaining this system included a list of general category items that will normally be exempt from traceability requirements. A second letter requesting the addition of specific items to the "Exempt Parts List" was also submitted to NASA.

## Inspection Planning

The inspection planning effort was accomplished through use of Inspection and Test Instruction Sheets (ITI's). The Fabrication Assembly Inspection Record (FAIR) system now being implemented in manufacturing will replace the ITI sheets as the cognizant inspection document.

## Quality Control Laboratory

The first adhesive bonded assembly for the Apollo test requirements program was initiated. The program incorporates a new type of structural adhesive. The laboratory is qualifying the required materials and is assisting manufacturing in the process used during fabrication.

Radiographic films for the initial receival of aluminum 2014T-6 alloy forgings used for the Apollo command module have been received. Appearance

indicates that these forgings will be crack-sensitive when welded. Recommendations for the disposition of these forgings and for plans to correlate the properties and crack susceptibility through the weld are being studied. Some of the parts may be satisfactory for use in the Apollo test requirements program.

The first two shipments of titanium alloy (6A1-4V) welded tubing were acceptance tested. Samples failed to meet specification requirements on the flattening test, and testing is continuing for evaluation studies. Severity of the flattening test will be reduced or vacuum annealing will be conducted before roll planishing and sizing, which will be followed by a stress relief treatment. The laboratory is directing its efforts toward resolving the engineering changes to complete the acceptance testing of the tubing.

## Quality Control Representatives at Subcontractors

Quality control representatives have been assigned to Thiokol Corporation and Minneapolis-Honeywell. Resident quality control representatives are now assigned to 9 of the 10 major subcontractors, with a representative at Avco still to be assigned.

## Quality Evaluation and Audit

Sixty-one performance audits consisting of 641 observations were conducted. Corrective/preventive action was initiated on 60 items. Action was completed on 20 items with remedial action in progress on the remainder. Three reaudits completed in previously discrepant areas revealed that all previous deficiencies had been corrected. Quality control laboratory evaluation of 38 parts were completed with satisfactory results.

# INSTRUMENTATION

## IN-FLIGHT TEST SYSTEM (IFTS) BREADBOARD

The operation of the IFTS breadboard shown in Figure 52 is explained in the block diagram (Figure 53). This breadboard will be used as an improved design of the IFTS as an example of the sequencing technique of test points.

## MAIN DISPLAY CONSOLE BREADBOARD

Figures 54 through 57 are photographs of the first main display console breadboard. This console incorporates easily obtainable components that perform the designed electronic functions.

## LOWER EQUIPMENT BAY MOCK-UP

A full scale mock-up of the lower equipment bay was constructed to study module mounting methods, interconnection techniques, and connector design criteria.

## INSERTION LOSS

A study of the insertion loss of the command module has been completed.

## NASA-FURNISHED EQUIPMENT

Scientific equipment to be furnished by NASA must be defined.

## IFTS POWER REQUIREMENTS

A review was made of IFTS power requirements using standard long-life (Minuteman) components. A total of 177 peak watts is presently required.

## LOGIC AND SWITCHING

Development of test logic simulation and switching circuitry for use with the IFTS was started with laboratory fabrication and test support.

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The roll simulator for the TR-48 computer was begun, and development of the control and display system was started in breadboard form.

## BACK-UP ENTRY DISPLAY

Figure 58 is a photograph of the mock-up of the back-up entry display. This mock-up will be used as a concept display.

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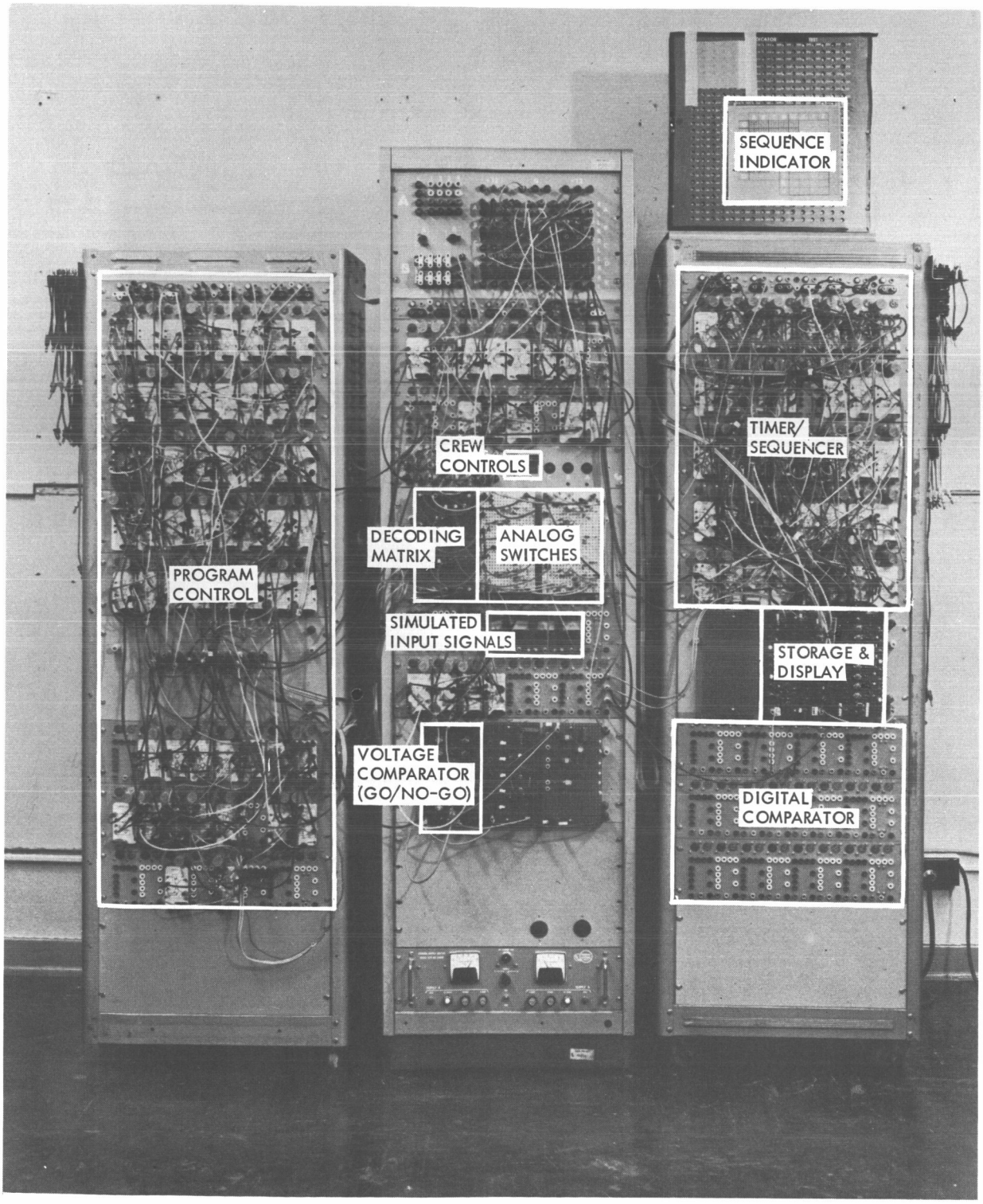


Figure 52. In-Flight Test System

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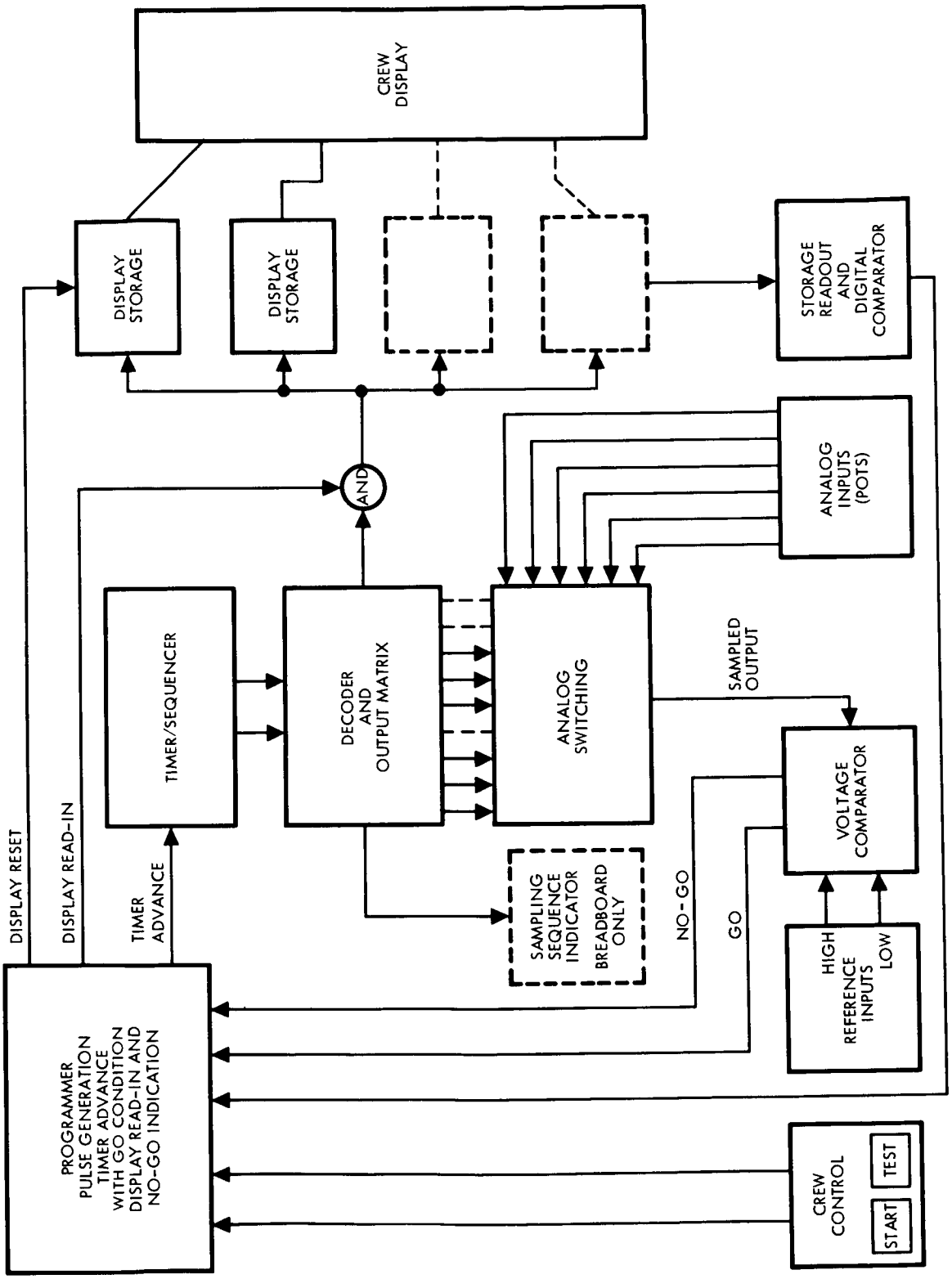


Figure 53. Preliminary Breadboard In-Flight Test System



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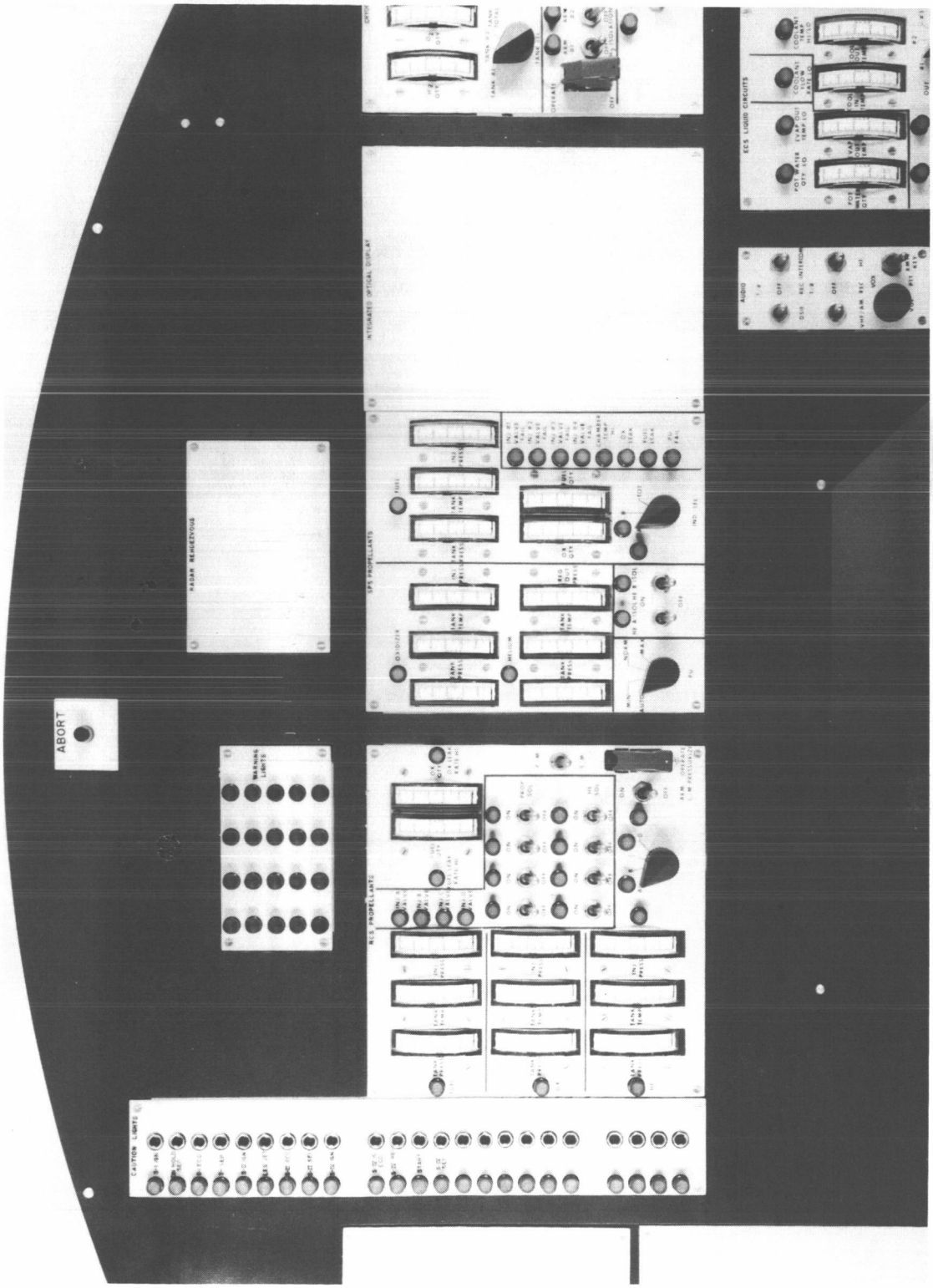


Figure 54. Main Display Console (Center Section)

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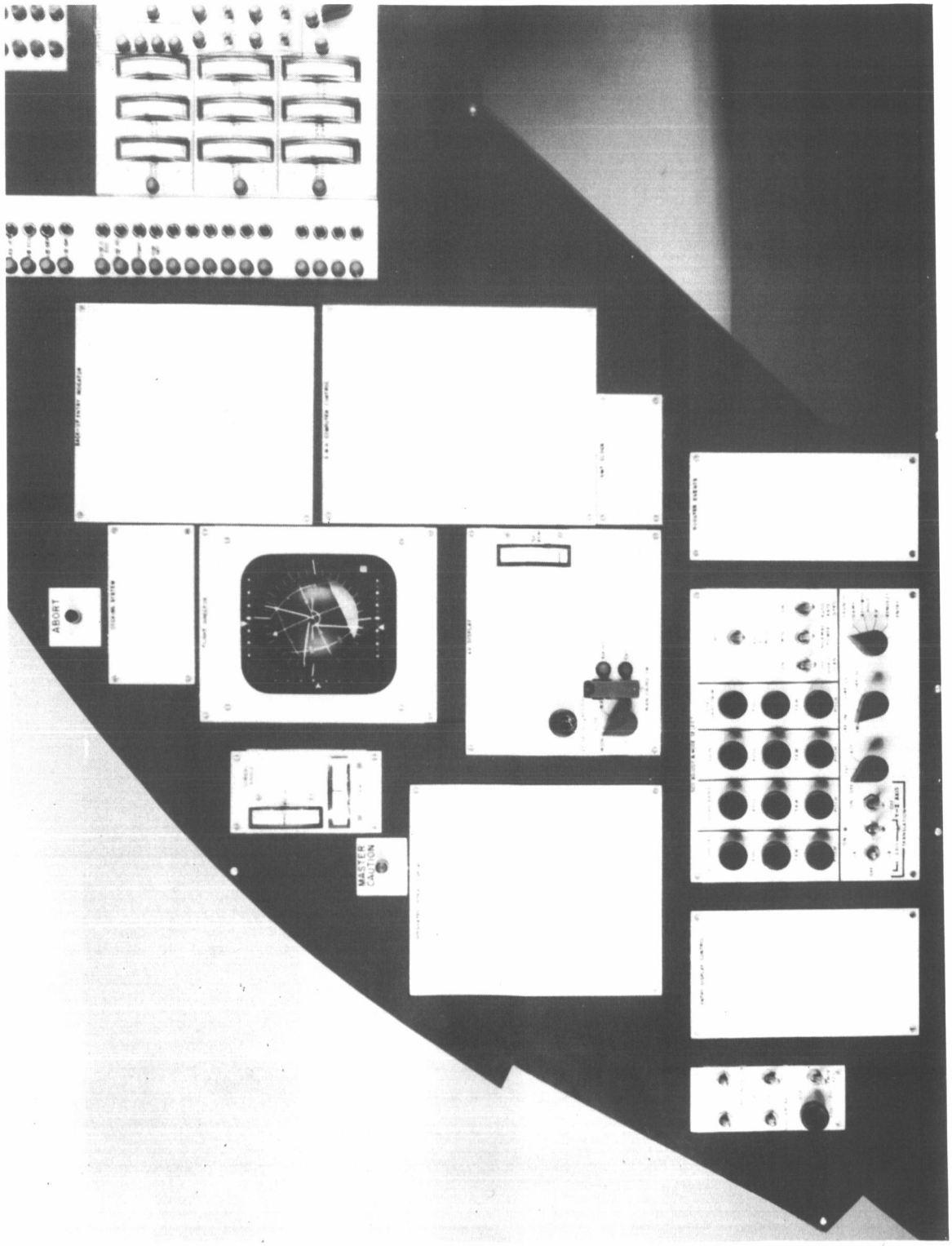


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Figure 55. Main Display Console (Left Section)



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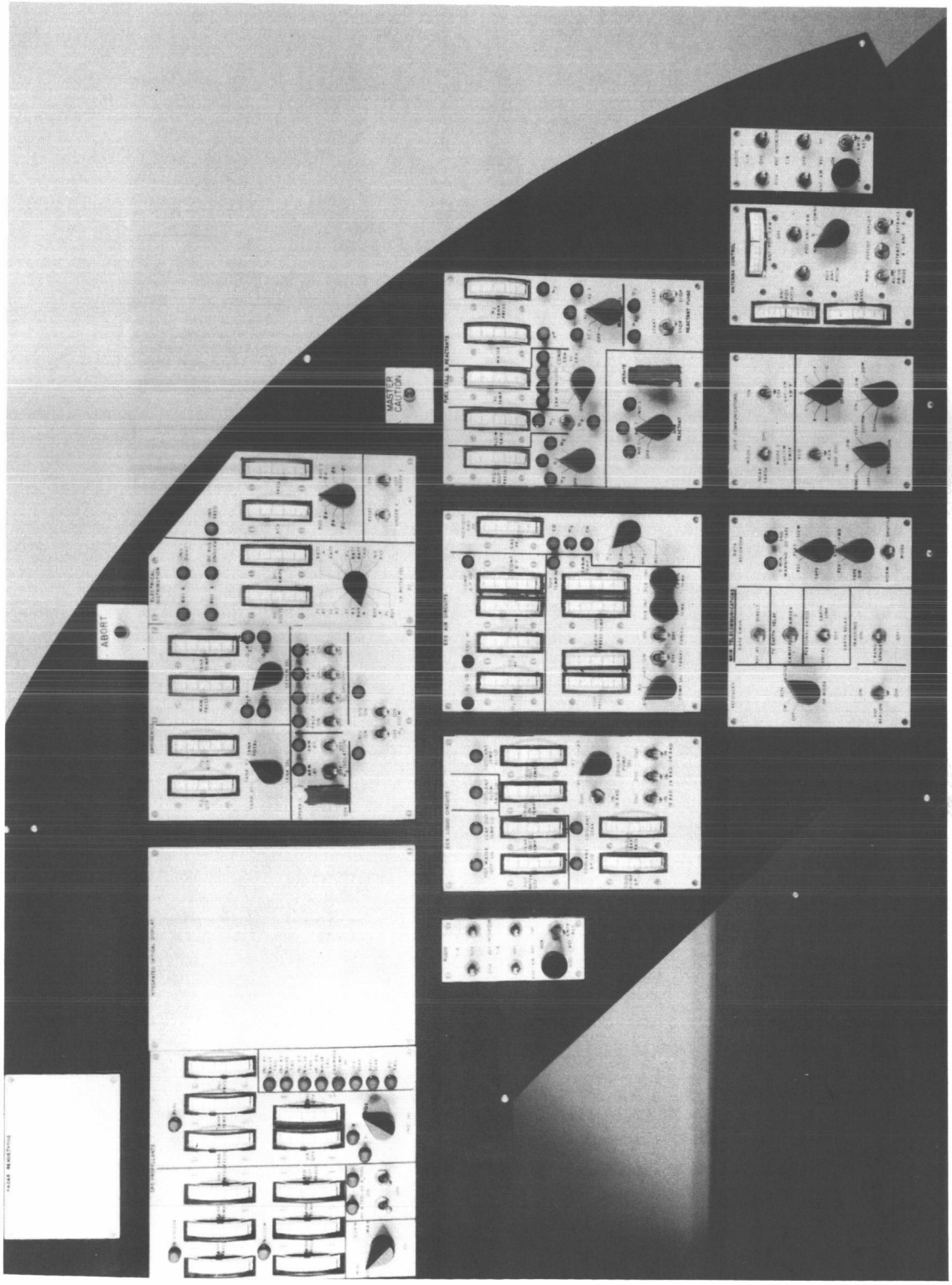


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Figure 56. Main Display Console (Right Section)



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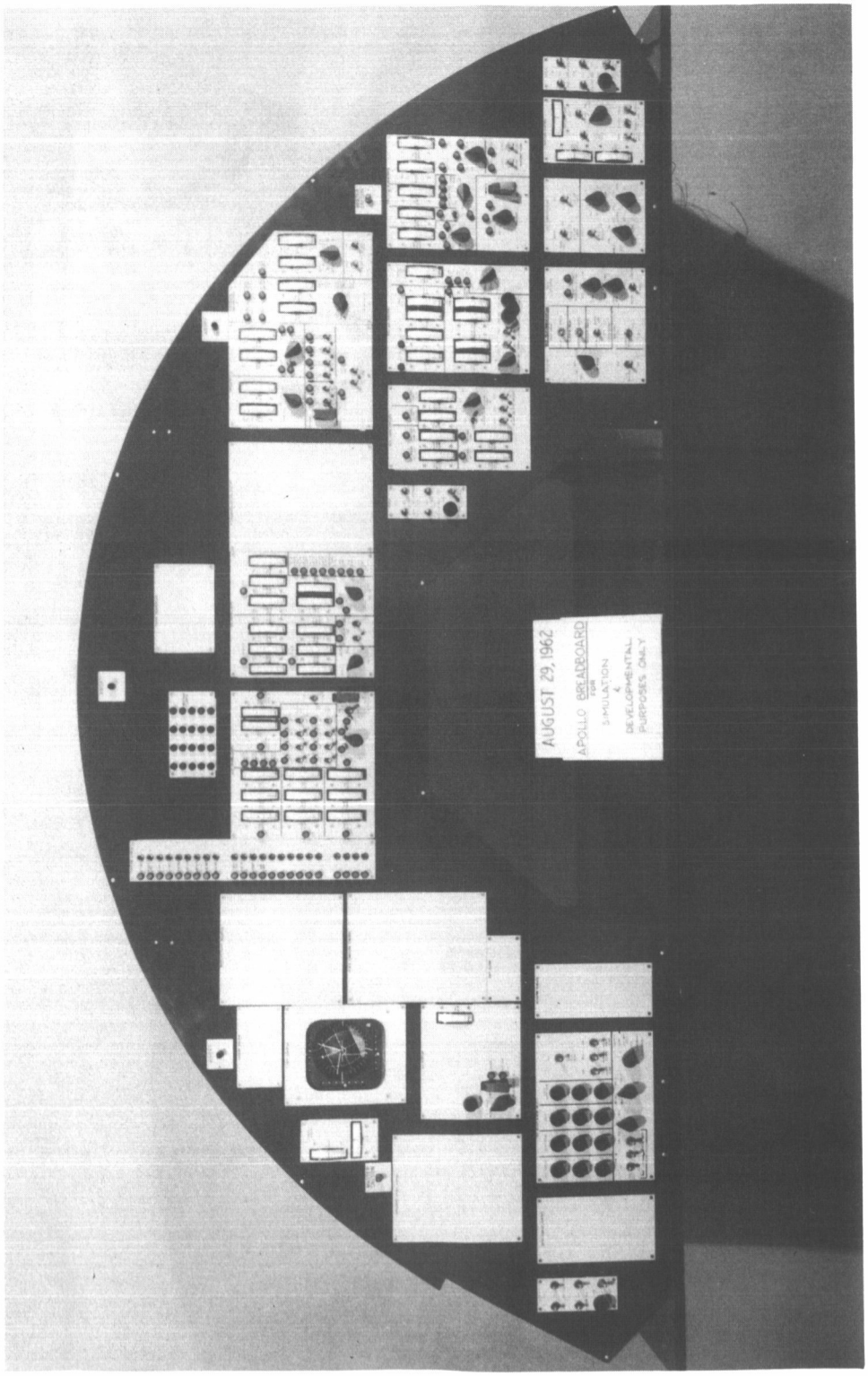


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Figure 57. Main Display Console (Aggregate Complete)



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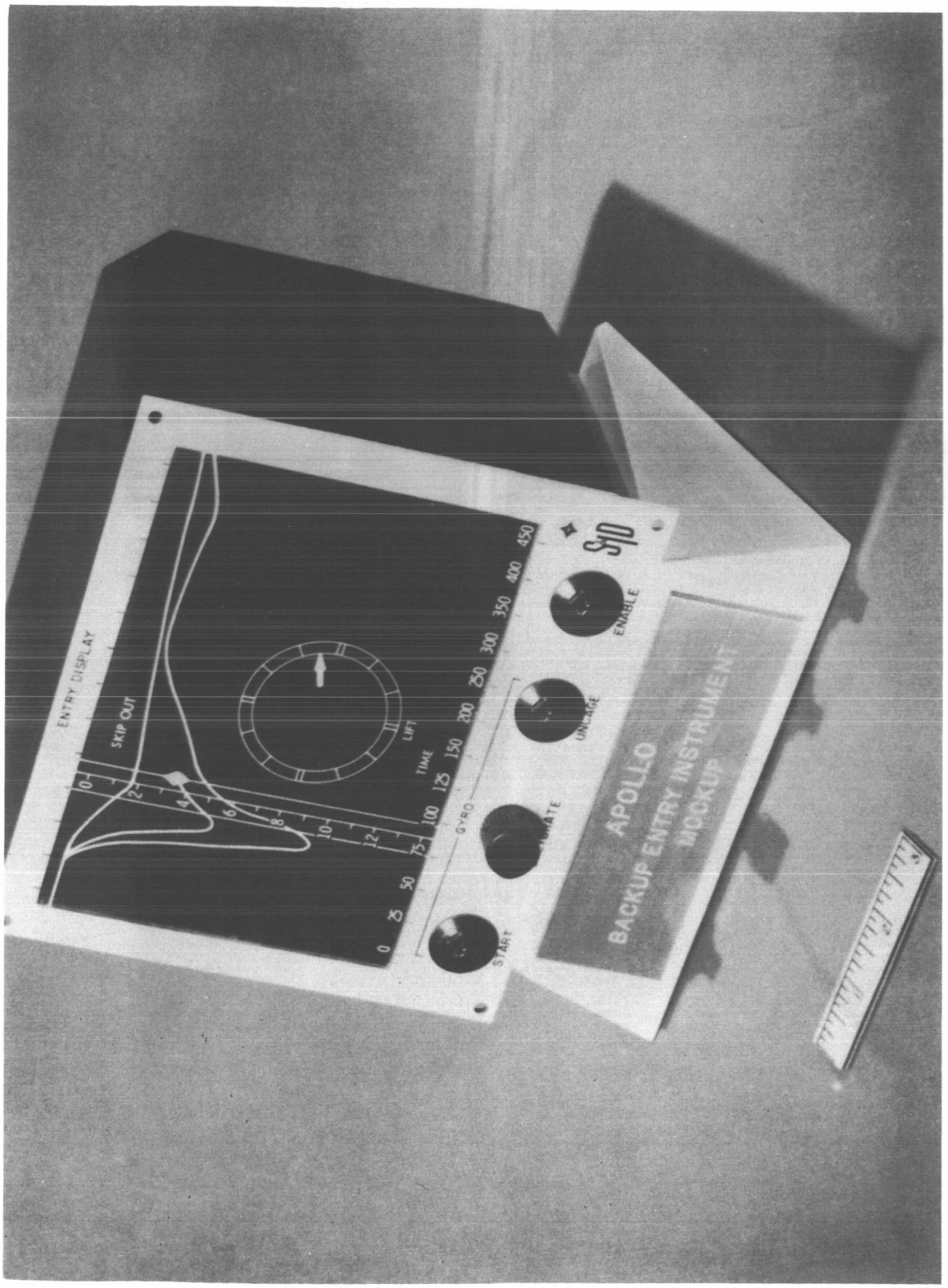


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Figure 58. Backup Entry Instrument Mockup



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# STABILIZATION AND CONTROL

## STABILIZATION AND CONTROL SYSTEM DESIGN

The stabilization and control system (SCS) over-all block diagram presented in Figure 59 shows the signal flow throughout the SCS system. All of the major elements in a complete SCS system are shown in proper relation to the over-all system. The functional modes of the SCS are presented in Figure 60, as related to particular Apollo segments and missions. Command functions as well as controlled variables common to these segments and missions are shown, together with the reference frame and prime sensor. Figure 61 correlates the functional modes with the modes that are currently being mechanized in the design.

Figure 62 outlines the control signal interfaces between the navigation and guidance system, the SCS, and the propulsion system. Forces and torques are shown acting through the spacecraft to produce detectable motions of the inertial instruments located in the navigation and guidance and the SCS equipment. Manual control requirements for particular segments of a mission are illustrated in Figure 63 Modes which are applicable for particular mission segments and the type of control required during that segment are also shown.

### Control Mode

Functional block diagrams are being drawn for each SCS operational mode. These individual diagrams will then be incorporated, through the necessary switching, into one over-all SCS functional block diagram. Status of individual diagrams is given in Table 14.

## SOLENOID TESTS

A key factor in obtaining a low impulse is the operating time of the solenoid valves. A fast response solenoid valve should reduce the minimum impulse capability. Techniques for decreasing the response time are being studied, one of which is the use of a single-coil solenoid valve. This should reduce the valve size and valve inductance, thereby decreasing the response time. Determination of series or parallel connection of solenoids is underway.

An evaluation test program for the reaction jets and thrust vector control system was outlined.

Preliminary requirements of SCS testing on the propulsion spacecraft was determined.

Table 14. Status of Block Diagrams

| No. | Control Mode Description | Status | Located on Mode-Select Panel |
|---|---|---|---|
| 1 | Launch | Complete | X |
| 2 | Coast - SCS | Complete | X |
| 3 | Local Vertical - SCS | Complete | X |
| 4 | Sun Acquire | Complete | X |
| 5 | Sun Hold (Automatic after Sun Acquire) | Complete | |
| 6 | BMAG - $\Delta$ V Correction | Complete | X |
| 7 | Attitude Hold - G&N | Complete | X |
| 8 | IMU - Correction | Complete | X |
| 9 | Entry - G&N Prior to g build-up | Complete | X |
| 10 | Control Stick Steering-Rotational | Complete | |
| 11 | Rendezvous | Not defined | X |
| 12 | Orientation for $\Delta$V - BMAG | Incomplete | X |
| 13 | Orientation for $\Delta$V - IMU | Incomplete | X |
| 14 | Entry - G&N after g build-up | Incomplete | X |
| 15 | Float - Switches R, P, and Y Jets off | Incomplete | X |
| 16 | Damp (Automatic after S-II and S-IV Separation) | Incomplete | |
| 17 | Manual Translational Control | Incomplete | |

## EARTH ORBITAL MISSION CONTROL SYSTEM STUDY

Figure 64 is a block diagram of the simulated pitch attitude SCS. The roll and yaw channels are similar.

Figure 65 illustrates the yaw control system response that damps out initial tumbling rates of 10 degrees per second in roll or yaw. Such tumbling might result from separation from the booster stage or from propulsion system operation. The effects of cross products of inertia give a yaw response from initial tumbling in roll, but it is quickly damped out. A smaller dead-band than the 5 degrees indicated would further limit the cross-coupling effects.

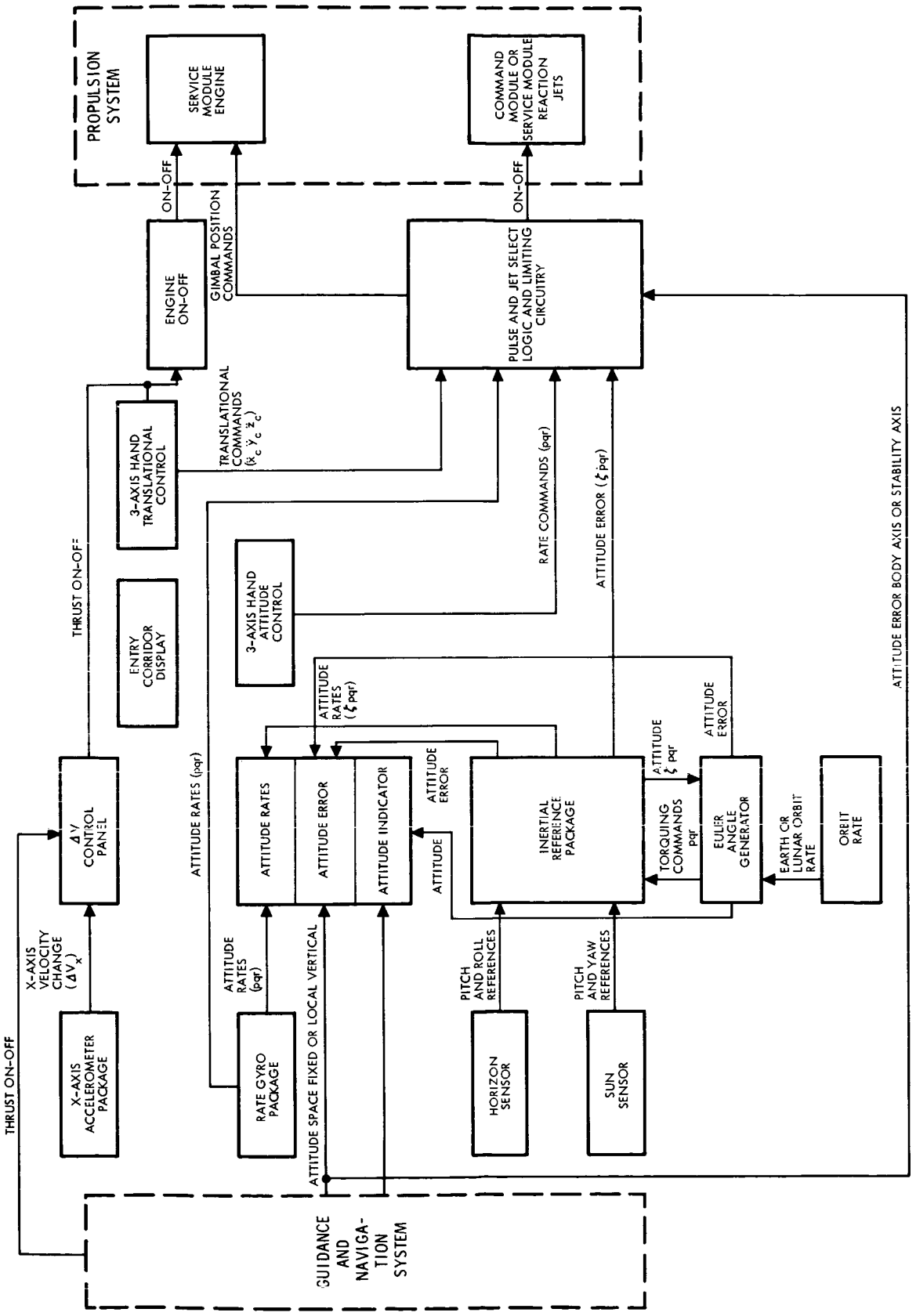


Figure 59. Stabilization Control System Overall Block Diagram

| NO. | MODE NAME | SEGMENT-MISSION | | MONITORED/ CONTROLLED VARIABLE | COMMAND SOURCE | REFERENCE FRAME | VARIABLE SENSED BY | INNER STABILITY LOOP | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | RATE | | ATTITUDE | |
| | | | | | | | | FEEDBACK QUANTITY | SENSOR | FEEDBACK QUANTITY | SENSOR |
| 1 | STANDBY | BOOST | ALL | 3-AXIS ATTITUDE | MONITORED ONLY | INERTIAL | GUIDANCE AND NAVIGATION (INERTIAL MEASURING UNIT) STABILIZATION CONTROL SYSTEM | DATA NOT AVAILABLE | DATA NOT AVAILABLE | DATA NOT AVAILABLE | DATA NOT AVAILABLE |
| 2 | GUIDANCE AND NAVIGATION ATTITUDE | EARTH ORBIT TRANSLUNAR TRANSEARTH LUNAR ORBIT | ALL ALL LUNAR LUNAR ORBIT LUNAR LANDING | 3-AXIS ATTITUDE | GUIDANCE AND NAVIGATION | PITCH AND YAW: LOCAL VERTICAL ROLL: INERTIAL | GUIDANCE AND NAVIGATION (INERTIAL MEASURING UNIT) | p, q, r | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | DATA NOT AVAILABLE | DATA NOT AVAILABLE |
| 3 | STABILIZATION CONTROL SYSTEM LOCAL VERTICAL | ALL ORBITAL SEGMENTS | ORBITAL MISSIONS AND LUNAR LANDING MODULE | 3-AXIS ATTITUDE | CREW HAND CONTROLLER | LOCAL VERTICAL | STABILIZATION CONTROL SYSTEM HORIZON SENSOR AND INERTIAL REFERENCE PLATFORM | p, q, r | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | DATA NOT AVAILABLE | DATA NOT AVAILABLE |
| 4 | STABILIZATION CONTROL SYSTEM INERTIAL | TRANSLUNAR TRANSEARTH | ALL LUNAR | 3-AXIS ATTITUDE | CREW HAND CONTROLLER | INERTIAL | STABILIZATION CONTROL SYSTEM INERTIAL REFERENCE PLATFORM | p, q, r | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | DATA NOT AVAILABLE | DATA NOT AVAILABLE |
| 5 | STABILIZATION CONTROL SYSTEM SUN ORIENT | TRANSLUNAR TRANSEARTH | ALL LUNAR | 3-AXIS ATTITUDE | PITCH AND YAW: SUN SENSOR ROLL: CREW | HELIOCENTRIC INERTIAL | PITCH AND YAW: SUN SENSOR ROLL: INERTIAL REFERENCE PLATFORM | p, q, r, FOR ACQUISITION ONLY | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | DATA NOT AVAILABLE | DATA NOT AVAILABLE |
| 6 | SEXTANT ATTITUDE | TRANSLUNAR TRANSEARTH | ALL LUNAR | 2-AXIS ATTITUDE (PITCH AND ROLL) | CREW AT SEXTANT STATION | VISUAL | VISUALLY THROUGH SEXTANT | UNDEFINED | UNDEFINED | DATA NOT AVAILABLE | DATA NOT AVAILABLE |
| 7 | GUIDANCE AND NAVIGATION SMALL $\Delta V$ | TRANSLUNAR TRANSEARTH | ALL LUNAR | 3-AXIS VELOCITY | GUIDANCE AND NAVIGATION | INERTIAL | GUIDANCE AND NAVIGATION (INERTIAL MEASURING UNIT PLATFORM ACCELERATION) | p, q, r | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | $\theta, \psi, \phi$, | GUIDANCE AND NAVIGATION (INERTIAL MEASURING UNIT) |
| 8 | STABILIZATION CONTROL SYSTEM SMALL $\Delta V$ | TRANSLUNAR TRANSEARTH | ALL LUNAR | 3-AXIS VELOCITY | CREW | $V_x$-INERTIAL $V_y$ $V_z$ VISUAL | $V_x$: STABILIZATION CONTROL SYSTEM BODY MOUNTED ACCELERATION $V_y$, $V_z$- VISUAL | p, q, r | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | $\theta, \psi, \phi$, | STABILIZATION CONTROL SYSTEM (INERTIAL REFERENCE PLATFORM) |
| 9 | GUIDANCE AND NAVIGATION LARGE $\Delta V$ | ALL INJECTIONS TRANSLUNAR TRANSEARTH EARTH DEORBIT | ALL LUNAR EARTH ORBIT | 3-AXIS VELOCITY | GUIDANCE AND NAVIGATION | INERTIAL | GUIDANCE AND NAVIGATION (INERTIAL MEASURING UNIT PLATFORM ACCELERATION) | p, q, r | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | $\theta, \psi, \phi$, | GUIDANCE AND NAVIGATION (INERTIAL MEASURING UNIT) |
| 10 | STABILIZATION CONTROL SYSTEM LARGE $\Delta V$ | ALL INJECTIONS TRANSLUNAR TRANSEARTH EARTH ORBIT | ALL LUNAR EARTH ORBIT | 1-AXIS VELOCITY ($V_x$) | CREW | INERTIAL | STABILIZATION CONTROL SYSTEM BODY MOUNTED ACCELERATION | p, q, r | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | $\theta, \psi, \phi$, | STABILIZATION CONTROL SYSTEM (INERTIAL REFERENCE PLATFORM) STABILIZATION CONTROL SYSTEM (INERTIAL REFERENCE PLATFORM) AND HORIZON SENSOR |
| 11 | GUIDANCE AND NAVIGATION ENTRY | ENTRY | ALL | 1-AXIS ATTITUDE (ROLL) | GUIDANCE AND NAVIGATION | ENTRY REFERENCE FRAME | GUIDANCE AND NAVIGATION (INERTIAL MEASURING UNIT) AND COMPUTER) | p, q, r | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | DATA NOT AVAILABLE | DATA NOT AVAILABLE |
| 12 | STABILIZATION CONTROL SYSTEM ENTRY | ENTRY | ALL | 1-AXIS ATTITUDE (ROLL) | CREW | INTERIAL | STABILIZATION CONTROL SYSTEM INERTIAL REFERENCE PLATFORM | p, q, r | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | DATA NOT AVAILABLE | DATA NOT AVAILABLE |
| 13 | STABILIZATION CONTROL SYSTEM RENDEZVOUS AND DOCKING | TRANSLUNAR LUNAR ORBIT | LUNAR LANDING | 3-AXIS VELOCITY | CREW | VISUAL | VISUAL | p, q, r | STABILIZATION CONTROL SYSTEM RATE GYRO PACKAGE | $\theta, \psi, \phi$, | STABILIZATION CONTROL SYSTEM (INERTIAL REFERENCE PLATFORM) |

Figure 60. Stabilization Control System Functional Modes

| STABILIZATION CONTROL SYSTEM MECHANIZATION MODES | | STABILIZATION CONTROL SYSTEM FUNCTIONAL MODES | |
|---|---|---|---|
| NO. | NAME | NO. | NAME |
| 1 | STABILIZATION CONTROL SYSTEM MONITOR MODE | 1 | STANDBY |
| 2 | INERTIAL MEASURING UNIT ATTITUDE CONTROL MODE | 2 | GUIDANCE AND NAVIGATION ATTITUDE CONTROL |
| 3 | INERTIAL REFERENCE PLATFORM ATTITUDE CONTROL MODE | 4 | STABILIZATION CONTROL SYSTEM INERTIAL ATTITUDE CONTROL SEXTANT ATTITUDE CONTROL |
| 4 | INERTIAL REFERENCE PLATFORM LOCAL VERTICAL MODE | 3 | STABILIZATION CONTROL SYSTEM LOCAL VERTICAL ATTITUDE CONTROL |
| 5 | SUN HOLD MODE | 5 | STABILIZATION CONTROL SYSTEM SUN ORIENT |
| 6 | INERTIAL MEASURING UNIT ΔV MODE | 9 | GUIDANCE AND NAVIGATION LARGE ΔV VELOCITY CONTROL |
| 7 | INERTIAL REFERENCE PLATFORM ΔV MODE | 8 | GUIDANCE AND NAVIGATION SMALL ΔV VELOCITY CONTROL |
| 8 | INERTIAL MEASURING UNIT ENTRY MODE | 7 | STABILIZATION CONTROL SYSTEM SMALL ΔV VELOCITY CONTROL |
| 9 | INERTIAL REFERENCE PLATFORM ENTRY MODE | 10 | STABILIZATION CONTROL SYSTEM LARGE ΔV VELOCITY CONTROL |
| | | 11 | GUIDANCE AND NAVIGATION ENTRY ATTITUDE CONTROL |
| | | 12 | STABILIZATION CONTROL SYSTEM ENTRY ATTITUDE CONTROL |

Figure 61. Relation of Mechanization to Functional Modes

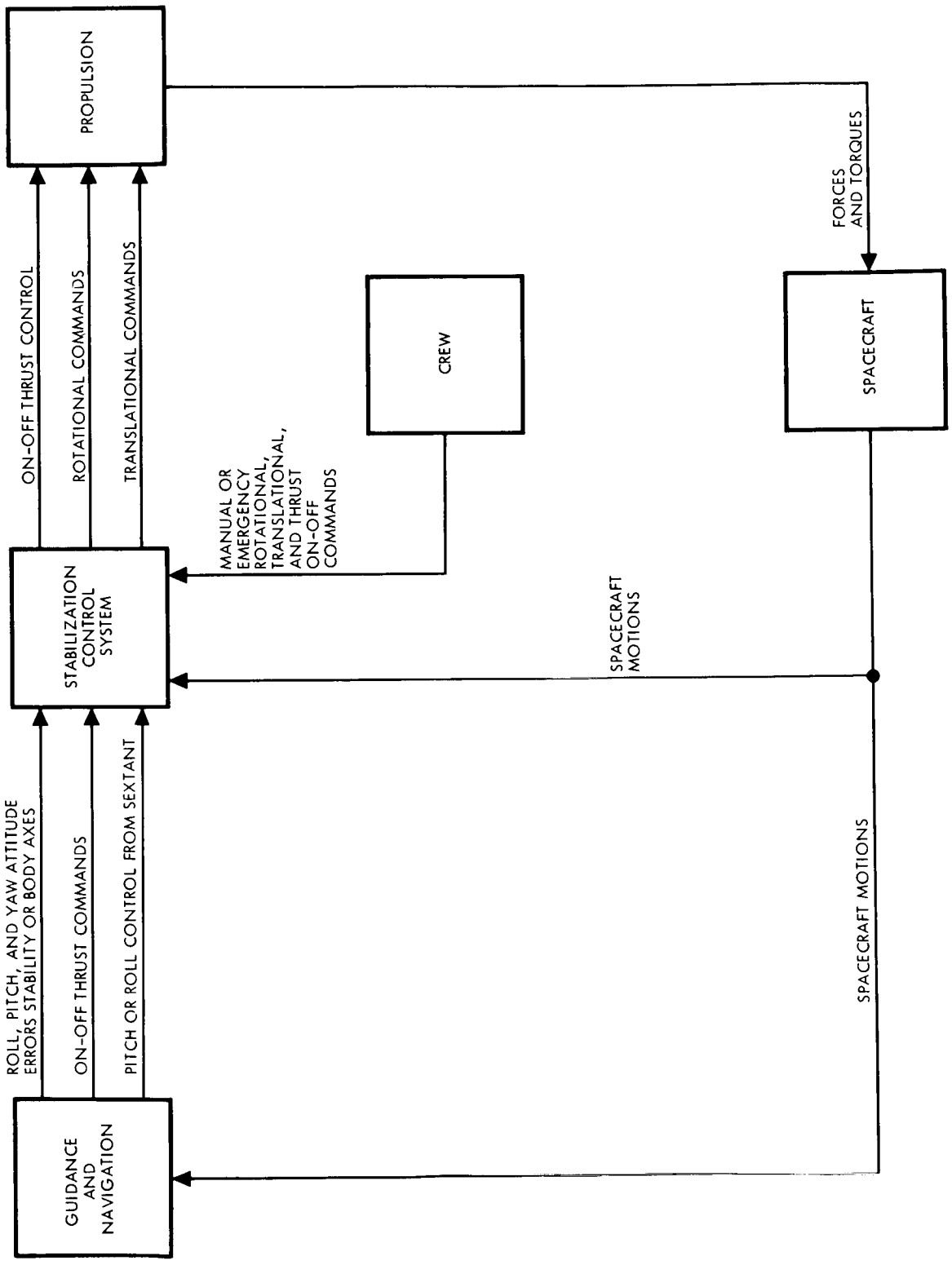


Figure 62. Control Signals

| SEGMENT | MODES SELECTION | ROTATION | TRANSLATION | MAIN ENGINE ON-OFF | MAIN ENGINE GIMBALING |
|---|---|---|---|---|---|
| LAUNCH | STABILIZATION CONTROL SYSTEM MONITOR | NO | NO | NO | NO |
| EARTH OR LUNAR ORBIT | INERTIAL MEASURING UNIT ATTITUDE CONTROL<br>INERTIAL REFERENCE PLATFORM ATTITUDE CONTROL<br>INERTIAL REFERENCE PLATFORM LOCAL VERTICAL | 3 AXES | + X ONLY | YES | YES |
| TRANSLUNAR OR TRANSEARTH | INERTIAL MEASURING UNIT ATTITUDE CONTROL<br>INERTIAL REFERENCE PLATFORM ATTITUDE CONTROL<br>SUN HOLD<br>INERTIAL MEASURING UNIT $\Delta V$<br>INERTIAL REFERENCE PLATFORM $\Delta V$ | 3 AXES | 3 AXES | YES | YES |
| ORBIT TRANSFERS | INERTIAL MEASURING UNIT $\Delta V$<br>INERTIAL REFERENCE PLATFORM $\Delta V$ | 3 AXES | + X ONLY | YES | YES |
| ORBIT INJECTION AND EJECTION | INERTIAL MEASURING UNIT $\Delta V$<br>INERTIAL REFERENCE PLATFORM $\Delta V$ | 3 AXES | + X ONLY | YES | YES |
| PRE-ENTRY | INERTIAL MEASURING UNIT ATTITUDE CONTROL<br>INERTIAL REFERENCE PLATFORM ATTITUDE CONTROL | 3 AXES | NO | NO | NO |

Figure 63. Manual Stabilization Control System Control Requirements

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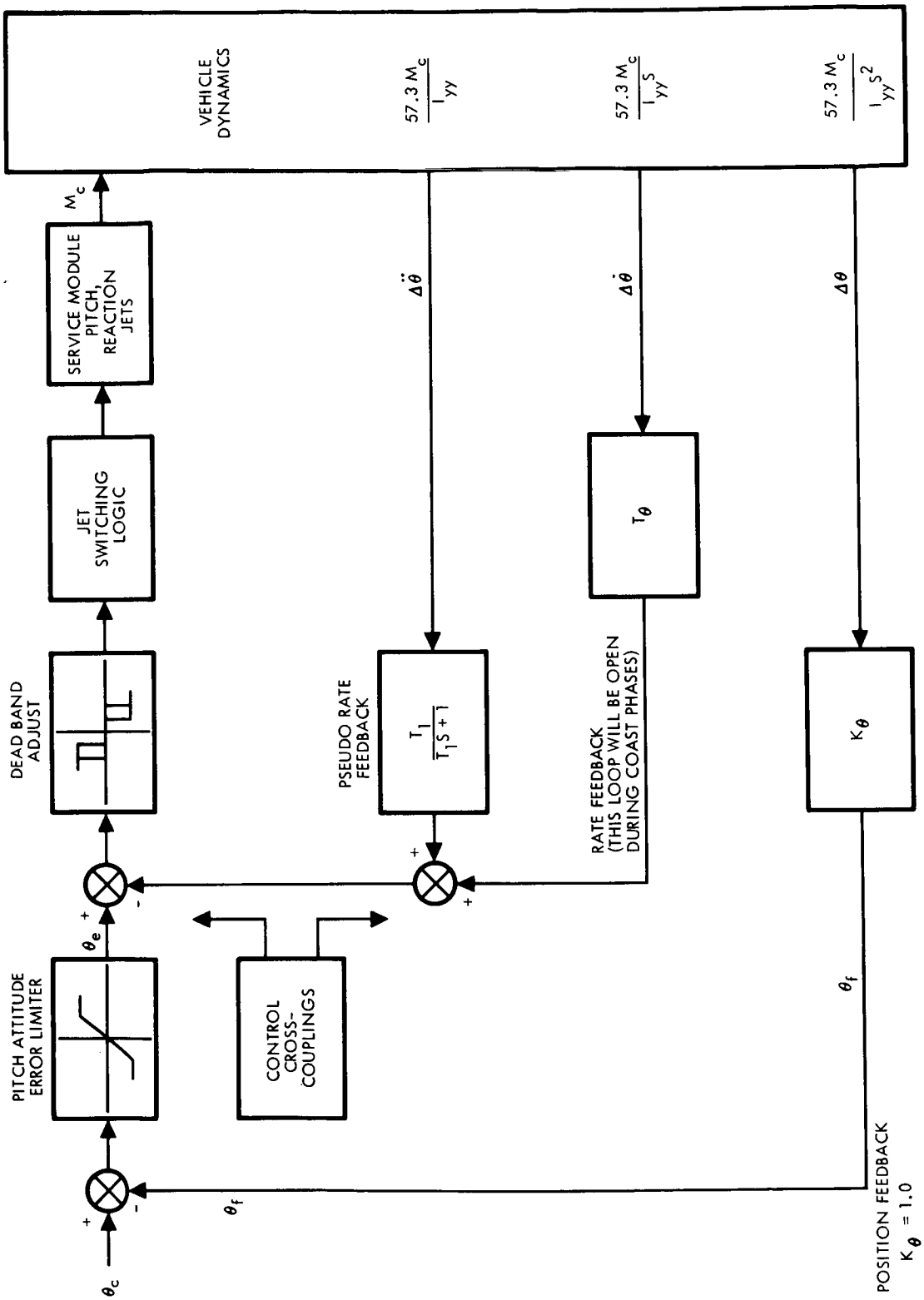


Figure 64. Revised Block Diagram

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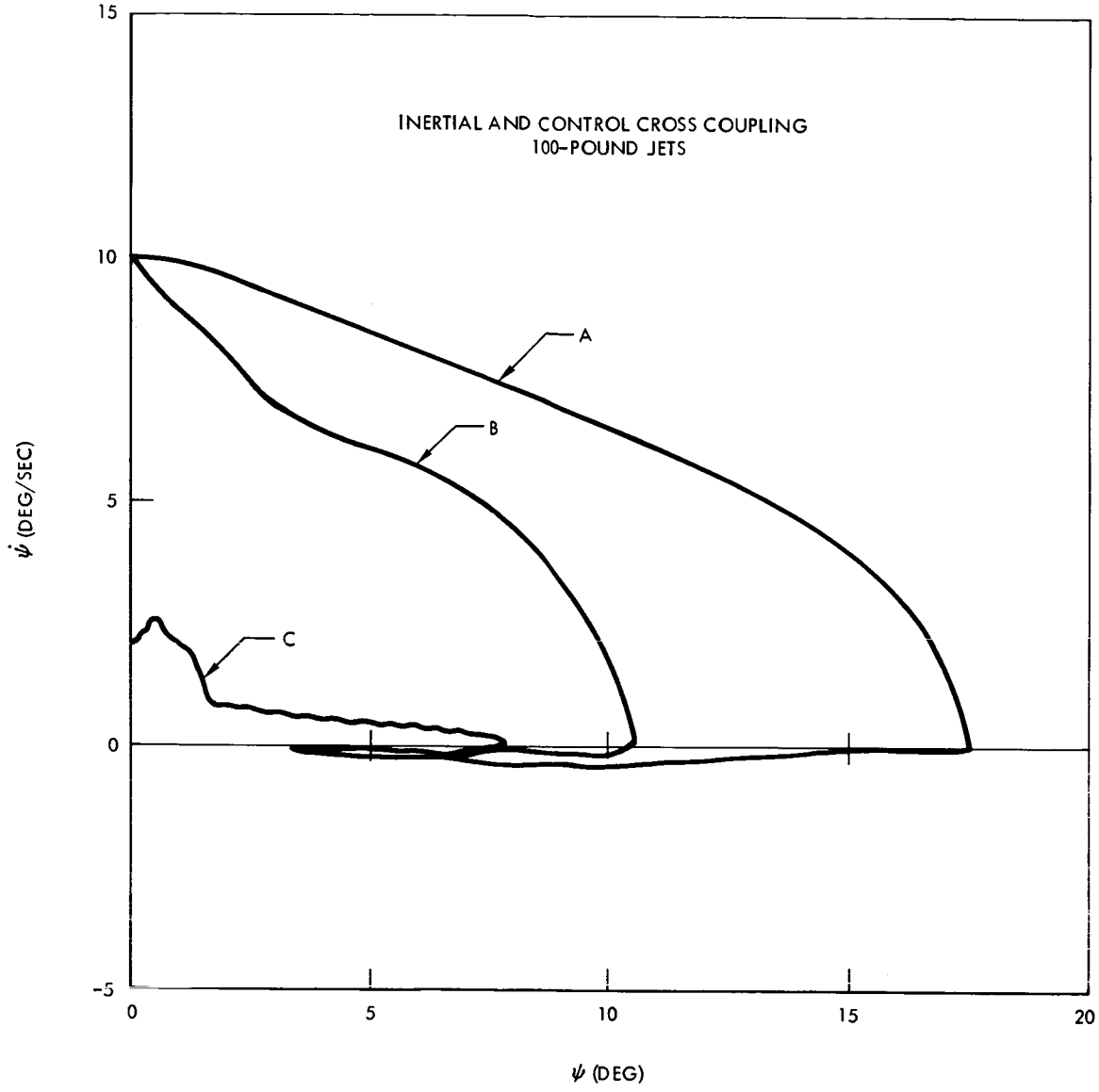


| CURVE | FUEL UNITS | INITIAL CONDITION | DEAD BAND | TIME CONSTANT |
|---|---|---|---|---|
| A | 11.19 | $\dot{\psi}=\dot{\phi}$ = 10 DEG/SEC | $\psi \epsilon$ DB = 5 DEG | 10 SEC |
| B | 4.31 | $\dot{\phi}$ = 10 DEG/SEC | $\psi \epsilon$ DB = 5 DEG | 10 SEC |
| C | 8.34 | $\dot{\psi}$ = 10 DEG/SEC | $\psi \epsilon$ DB = 5 DEG | 10 SEC |

Figure 65. Damping Out Tumbling Rates—Command Module/Service Module Configuration in Earth Orbit Yaw Channel

[redacted]

## PULSE MODULATION TECHNIQUES STUDY

Analog studies indicated that a steady-state disturbance torque should produce a residual attitude bias as shown in Figure 66. Again, positive correlation is shown between analog results and numbers calculated from the equation for bias.

The pseudo-rate system was shown to be stable. For large maneuvers, some sort of rate information (measured or derived) would be necessary to limit the overshoots.

## THRUST VECTOR CONTROL STUDY

Figure 67 is an example of analog simulation result from the thrust vector control study. The traces indicate that, although roll torque is high due to main-engine firing, cancelling effects occur that leave the residual roll rate near zero and the residual roll angle less than one degree.

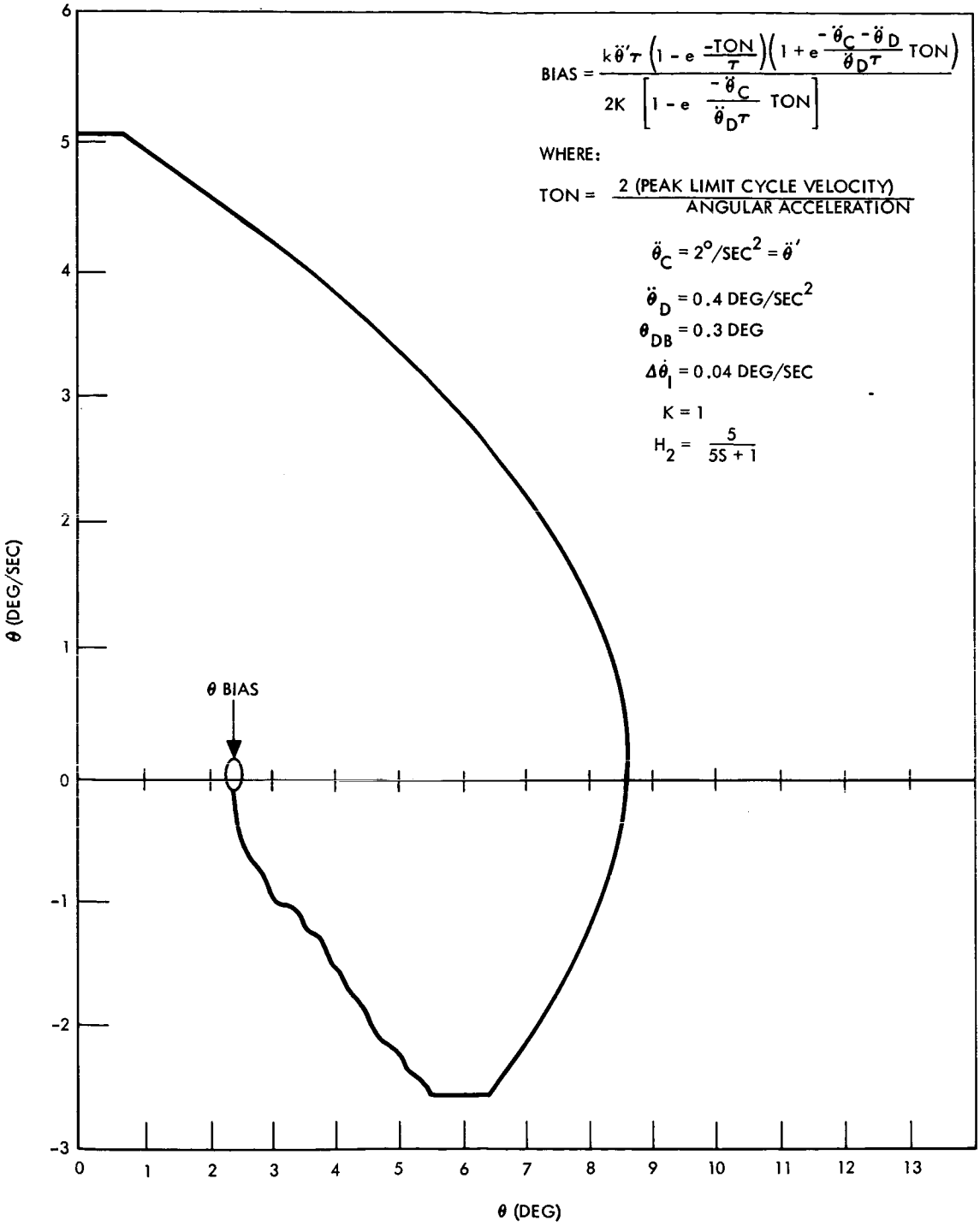


Figure 66. Effect of Steady Disturbance Torques

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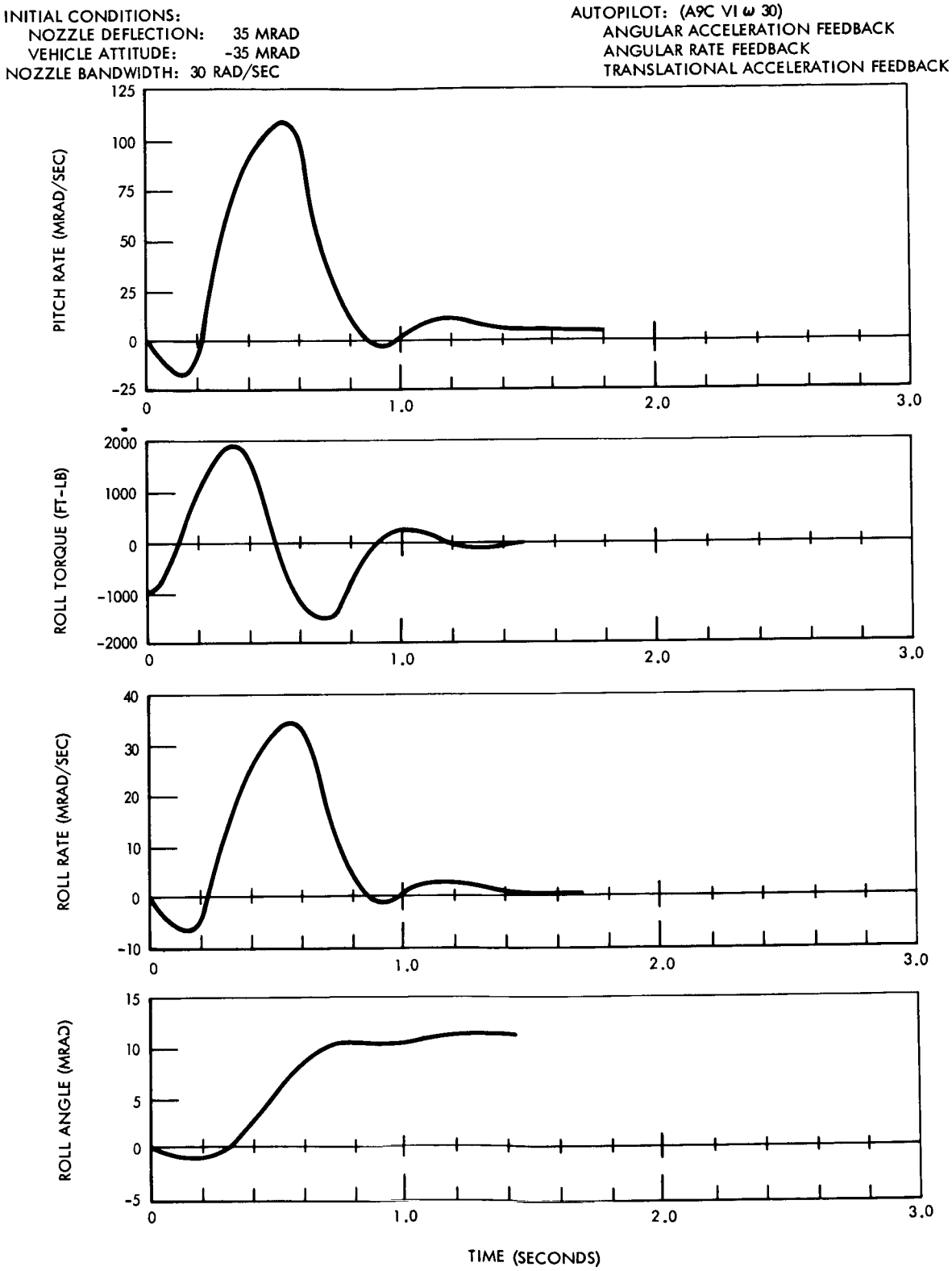


Figure 67. Response Characteristics to Initial Conditions Showing Negligible Magnitude of Disturbance Introduced into the Roll Channel by Firing the Main Engine



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# CREW PROVISIONS

## CREW EQUIPMENT DESIGN

The design control layout of the vision and lighting dome was completed.

The following human engineering drawings have been completed:

Command module attitude indicator
Controller, 3-axis - ring grip model
Controller translation - pencil stick type
Navigation and guidance display with controller
Seat support assembly
Indirect lighting control panel for the confinement mock-up
Canister, fecal, assembly of
Bag, fecal canister plastics, assembly of
Lighting system, mock-up
Yaw control panels
Lunar landing panel and control console
Lunar control console, mock-up 3
Lighting arrangement - primary area inboard
Lighting arrangement - primary area outboard
Lighting installation - air lock
Lighting installation - secondary area
Lighting installation - rest area

The following drawings have been completed:

Air lock valve control
Control valve air lock
Individual survival kit, mock-up 3
Individual radiation shield layout
Circular window for hatch

## CREW SUPPORT

A study to determine effects of crew motions inside the command module on spacecraft attitude control was completed.

Pressure seal zippers were investigated for use in sleeping restraint, in the rest compartment, and in the emergency pressure suit donning compartment.

The environmental control system (ECS) is being analyzed to determine inflight maintenance that can be accomplished by crewmen restrained in pressure suits and in a shirtsleeve environment.

An analysis of the air conditioning requirements for the Apollo evaluators was completed.

## DESIGN SUPPORT

A main panel arrangement layout is in progress, and individual systems panel faces are being designed. (See Figure 68 for current concept.) A cursory study to determine attitude presentation compatibility using a three axis ball with control action response and reference relationship is nearing completion.

A study to provide recommended relocations for the navigation and guidance panel was completed for presentation to NASA.

A list of tasks required for routine management of the electrical power system (EPS) is complete. A study of EPS failure modes was initiated to ascertain tasks and information displays required to avert failures.

A study to determine the revisions to the restraint couch to eliminate interference between center couch and navigation and guidance fixed optics was completed.

Manual overriders were defined for the control valves of the supercritical gas system located in the service module. Valve location is being established.

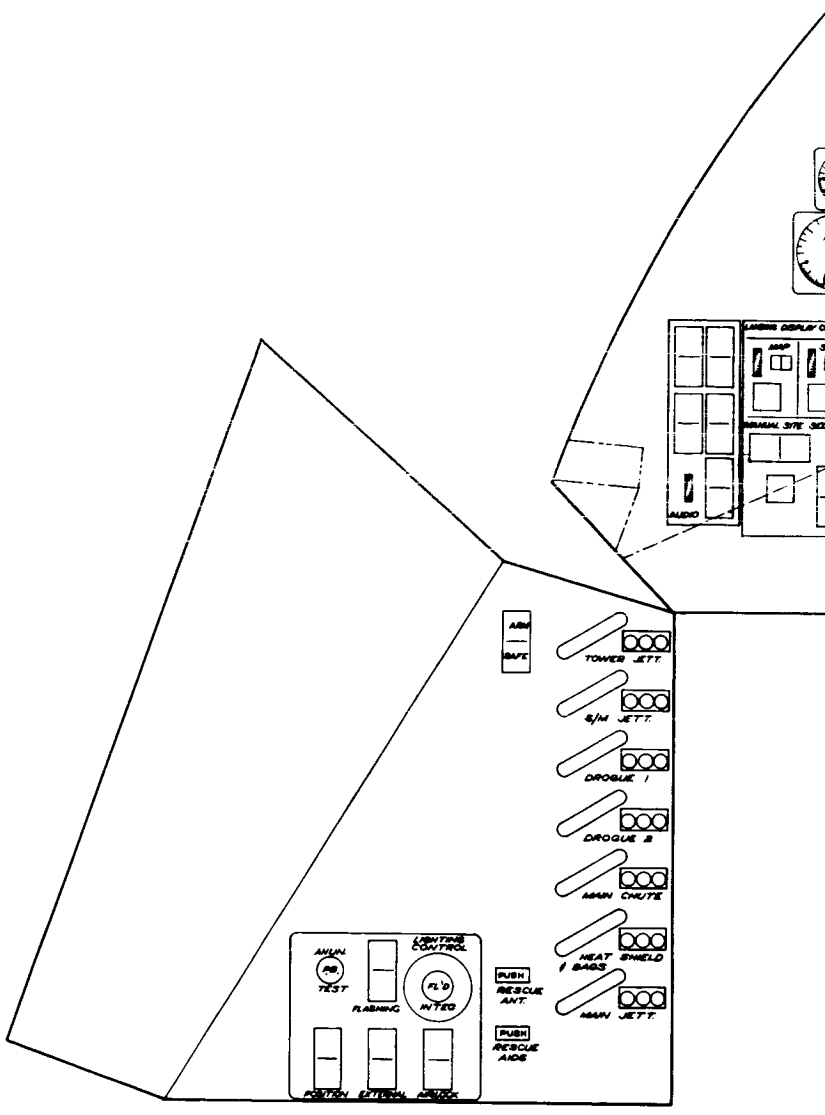
## GROUND SUPPORT AND CONTROL

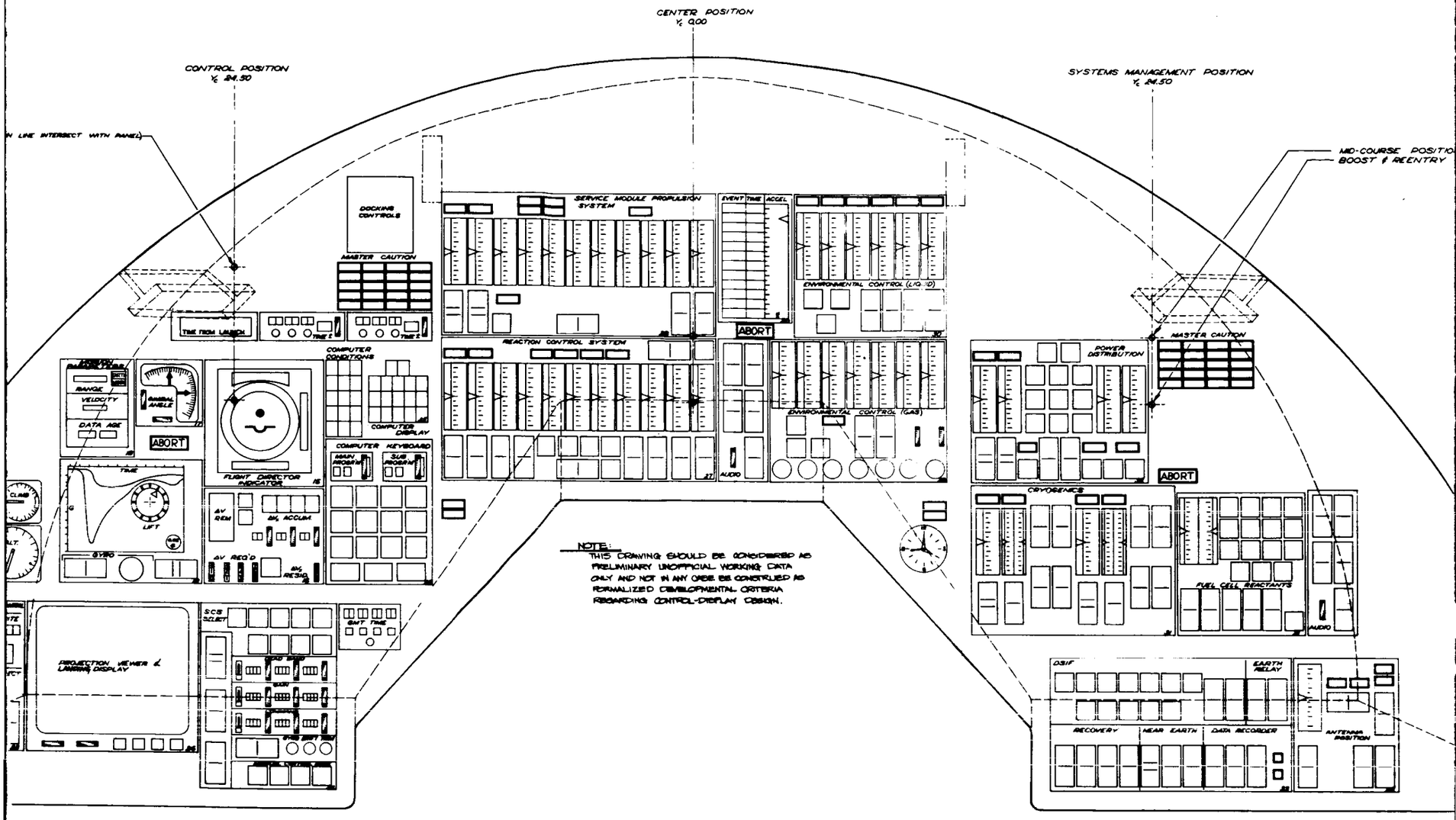
A concept of the service module reaction control system (RCS) checkout monitoring console in a full-scale cardboard panel was completed (Figures 69 and 70).

The panel studies for the biomedical console were completed.

A list of proposed safety procedures for AMR was completed.

DOCKING POSITION (NORMAL VISI






NOTE:
THIS DRAWING SHOULD BE CONSIDERED AS PRELIMINARY UNOFFICIAL WORKING DATA ONLY AND NOT IN ANY CASE BE CONSTRUED AS FORMALIZED DEVELOPMENTAL CRITERIA REGARDING CONTROL-DISPLAY DESIGN.

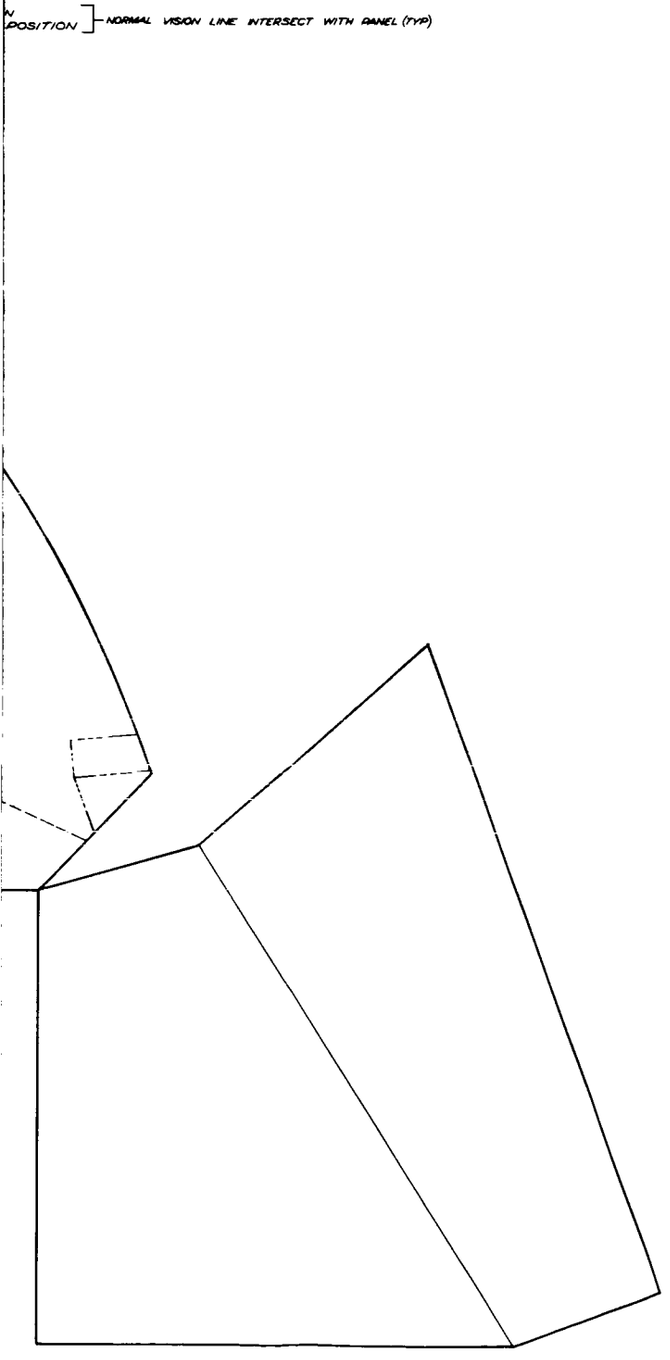



Figure 68. Display Panel Arrangement

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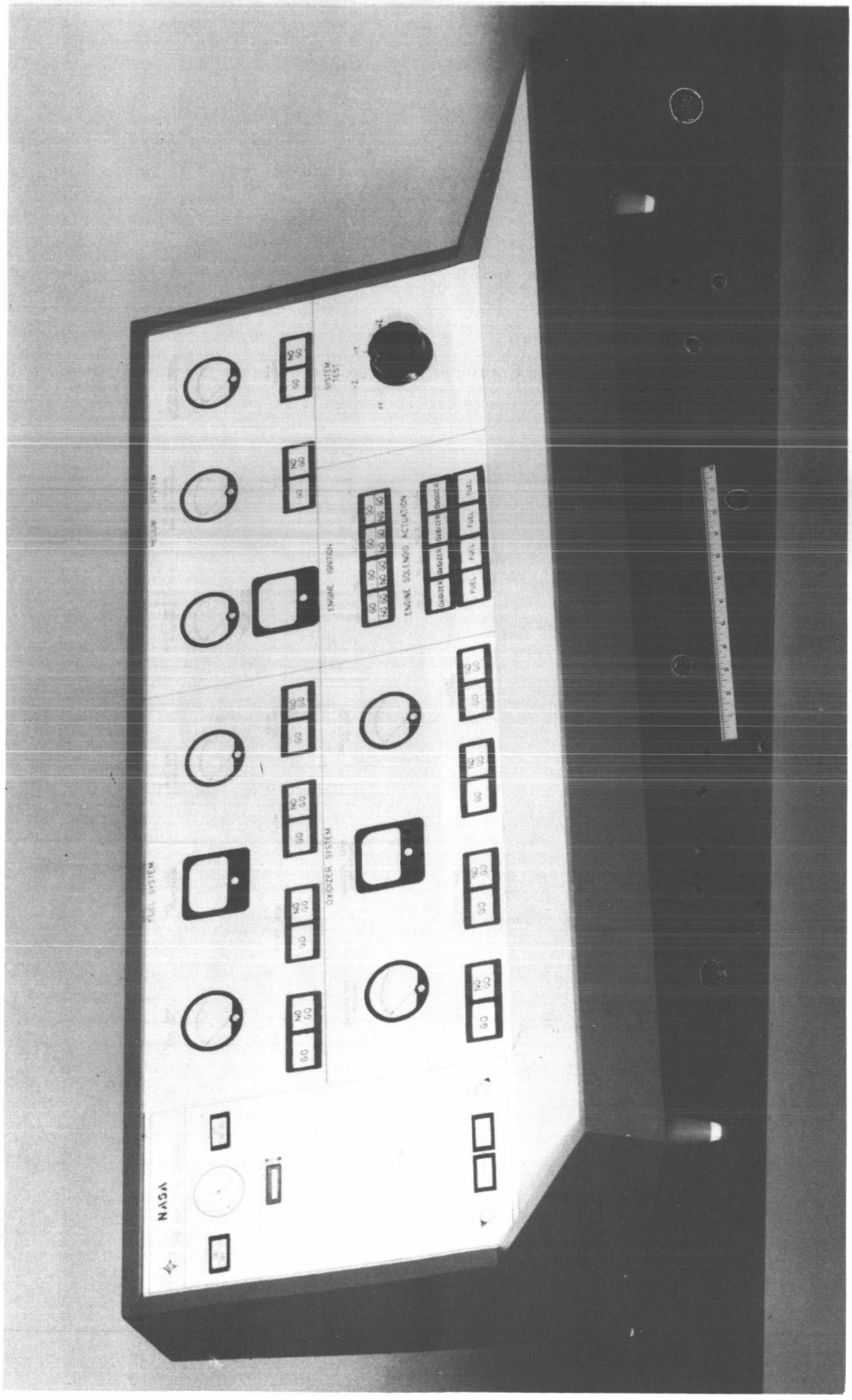


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Figure 69. Service Module Control System Checkout Monitoring Scale (A)



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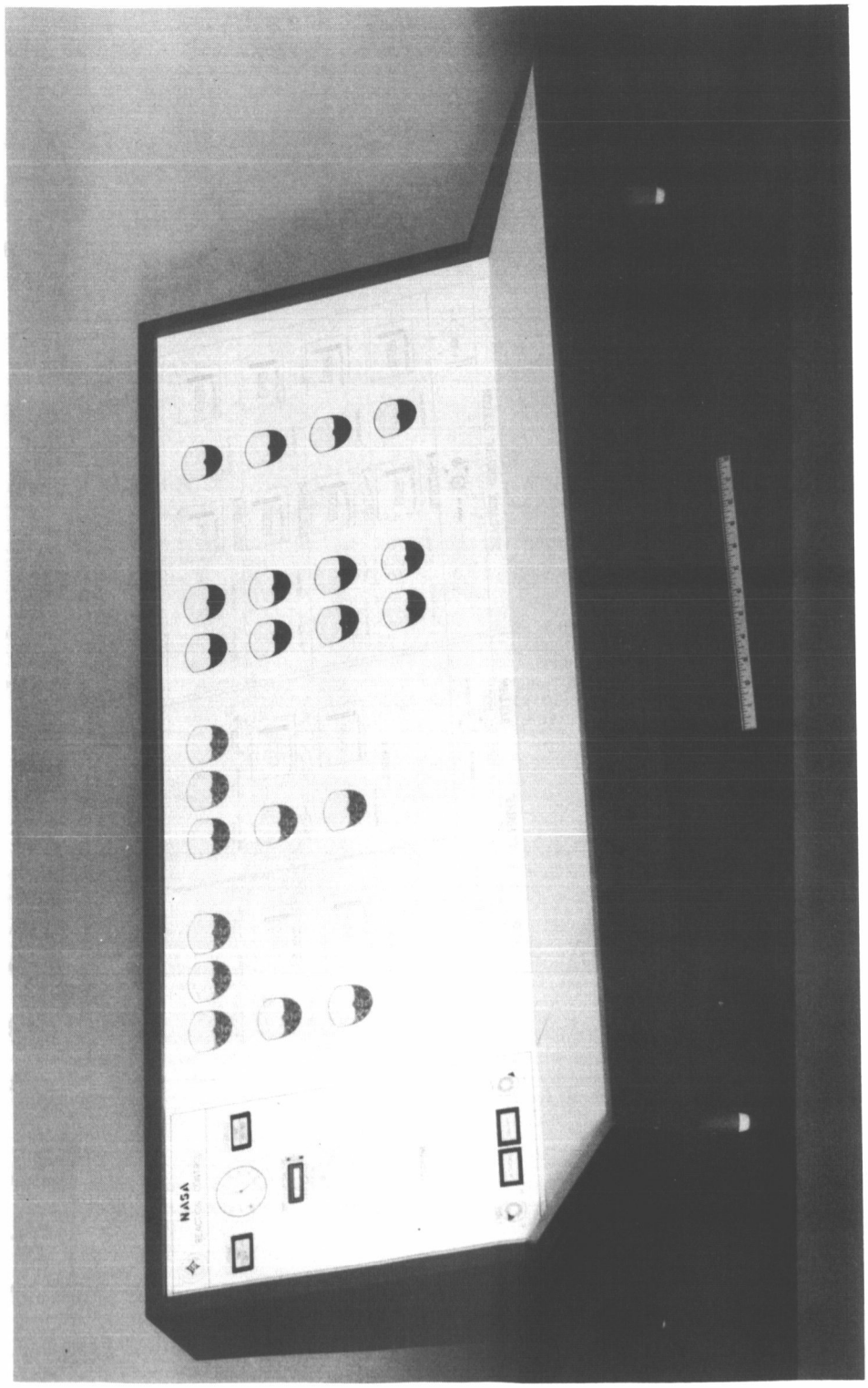


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Figure 70. Service Module Control System Checkout Monitoring Scale (B)

A preliminary life systems GSE operations and maintenance checklist was prepared.

A life systems concept of a checkout/monitor console for the propulsion system was completed on full-scale cardboard panel (Figure 70).

## CREW PERFORMANCE AND TRAINING

Simulation test plans were evaluated to determine which can be used to provide data on human performance in the Apollo missions. Out of approximately 60 test plans, 39 were judged to be capable of providing such data. Specific human performance test objectives were developed for each of these tests and were submitted as inputs to the quarterly revision of the Apollo General Test Plan.

A special lighting task group has recently completed a study to determine a time-line analysis of Apollo flight crew visual requirements for earth orbital, circumlunar, and lunar orbital missions.

The first revision of the flight crew performance specification was completed and was submitted to the specifications group. Earth orbital, circumlunar, lunar orbit, and lunar landing missions have been included in the specification.

A study to determine a method for validating flight crew performance was completed. If approved, the method is to be used in conjunction with the task analysis index to establish score values for the performance of crew functions.

Crew performance test design and requirements for Phase II of the 6.1 simulator study was completed (6-degree-of-freedom study).

## TASK DESIGN AND ANALYSIS

A study of the probable frequencies of crew ingress/egress during Apollo missions was completed.

An analysis was made of the command module pressure and temperature subsystem of the ECS to determine the corrective actions to be taken when instrumentation indicates a malfunction.

A proposed ingress-egress method and a telescoping air lock were evaluated.

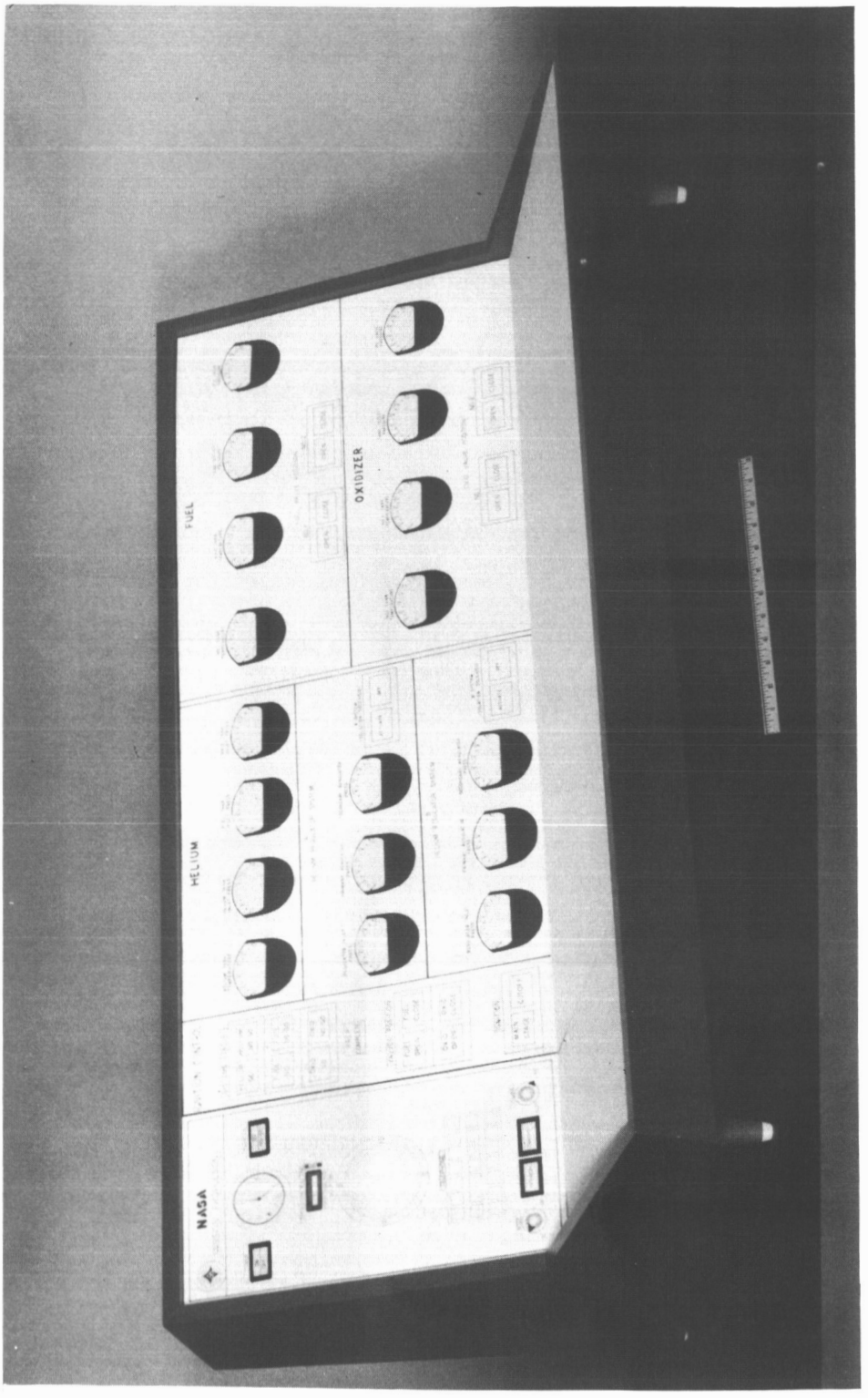


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Figure 71. Life Systems Checkout/Monitor Console

A series of flow diagrams have been completed showing actions to be taken when ECS test point instruments indicate abnormal operation of a subsystem or component.

A task analysis of all navigation functions performed at the lower station was completed. Control and display usage was specified on the basis of current information.

## BIOMEDICAL

A presentation on the biomedical aspects of the Apollo micrometeoroid problems was prepared.

An Apollo crew metabolic requirements summary based on considerations of diet and activity was completed. An analysis of the metabolic requirements of Glenn and Carpenter during orbital flights based on carbon dioxide production data was determined. A report has been submitted to the environmental control system group outlining the latest carbon dioxide requirements.

## OPERATIONS AND SAFETY

The hazards in bailout sequence under various modes of main chute deployment failures were investigated.

The human factor inputs were completed for redesign on the center hatch window.

The preliminary analysis of mission requirements of command module controls and displays as part of the task force effort was completed. This analysis has been integrated into a report discussing the technical aspects of command module control/display human factors development.

A report brochure was published depicting human factors aspects of GOSS simulation center requirements.

A report outlining criteria and procedures for the selection of test subjects for crew performance and flight simulation test programs was completed.

Processing and reduction of time-line data for evaluator 1 tests were completed. Air lock mobility tests of 10th and 90th percentile subjects in pressure suits were completed.

A lunar and earth orbital dynamics attitude control simulation was completed. Three pilots completed a total of five tests each.

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Life systems display and control requirements were completed for flight simulation studies.

Life systems instrumentation requirements for preliminary impact testing of boilerplate 1 were completed.

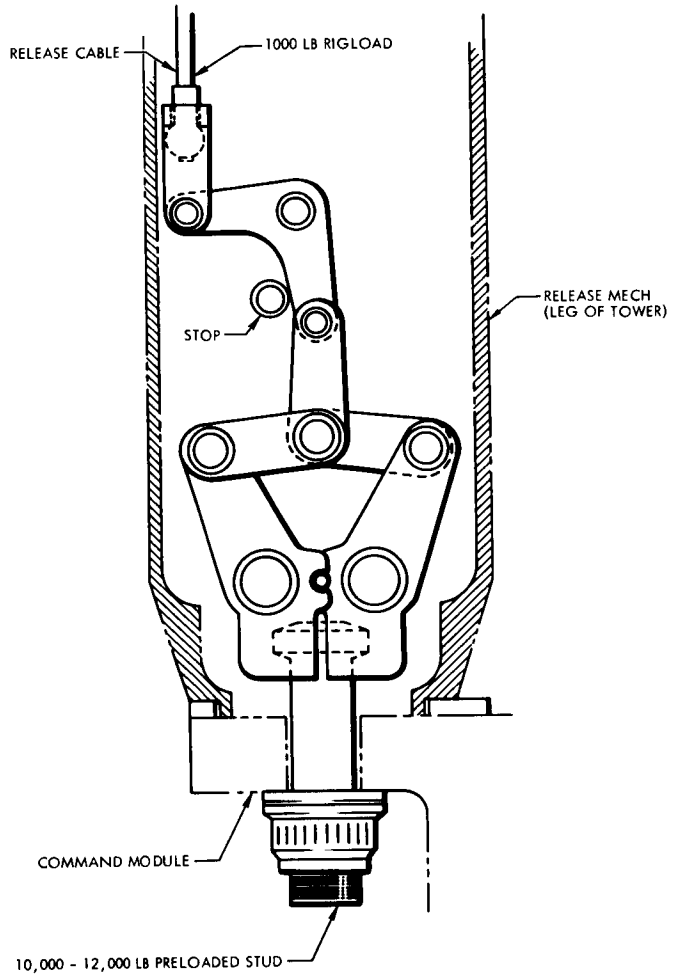
# LAUNCH ESCAPE SYSTEM

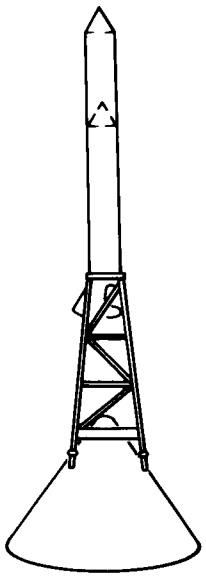
The launch escape system (LES) tower separation system is shown in Figure 72.

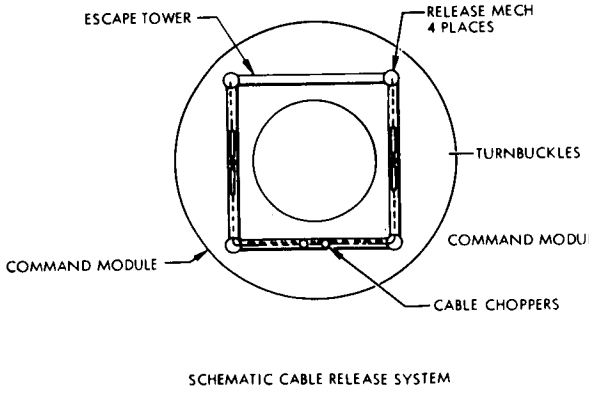
Figure 73 depicts the test set-up for the system.

Predicted performance curves for the pitch-control motor are presented in Figure 74. The motor features extreme simplicity of design and variable total-delivered impulse. The latter is achieved by final trimming of the propellant grain length prior to assembly.

New theoretical performance curves for the launch escape motor are shown in Figure 75. The nominal performance has been redefined as 155,000 pounds of thrust averaged over the first 1.5 seconds of operation at 70 F and 36,000 feet altitude. The current concept for the LES rocket motor is shown in Figure 76. Pertinent characteristics of the three LES solid-propellant motors are given in Table 15.



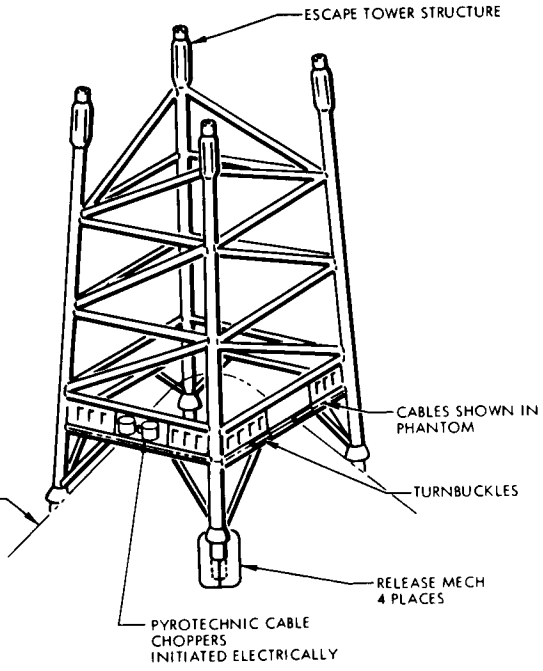




Figure 72. Schematic Escape Tower Separation System

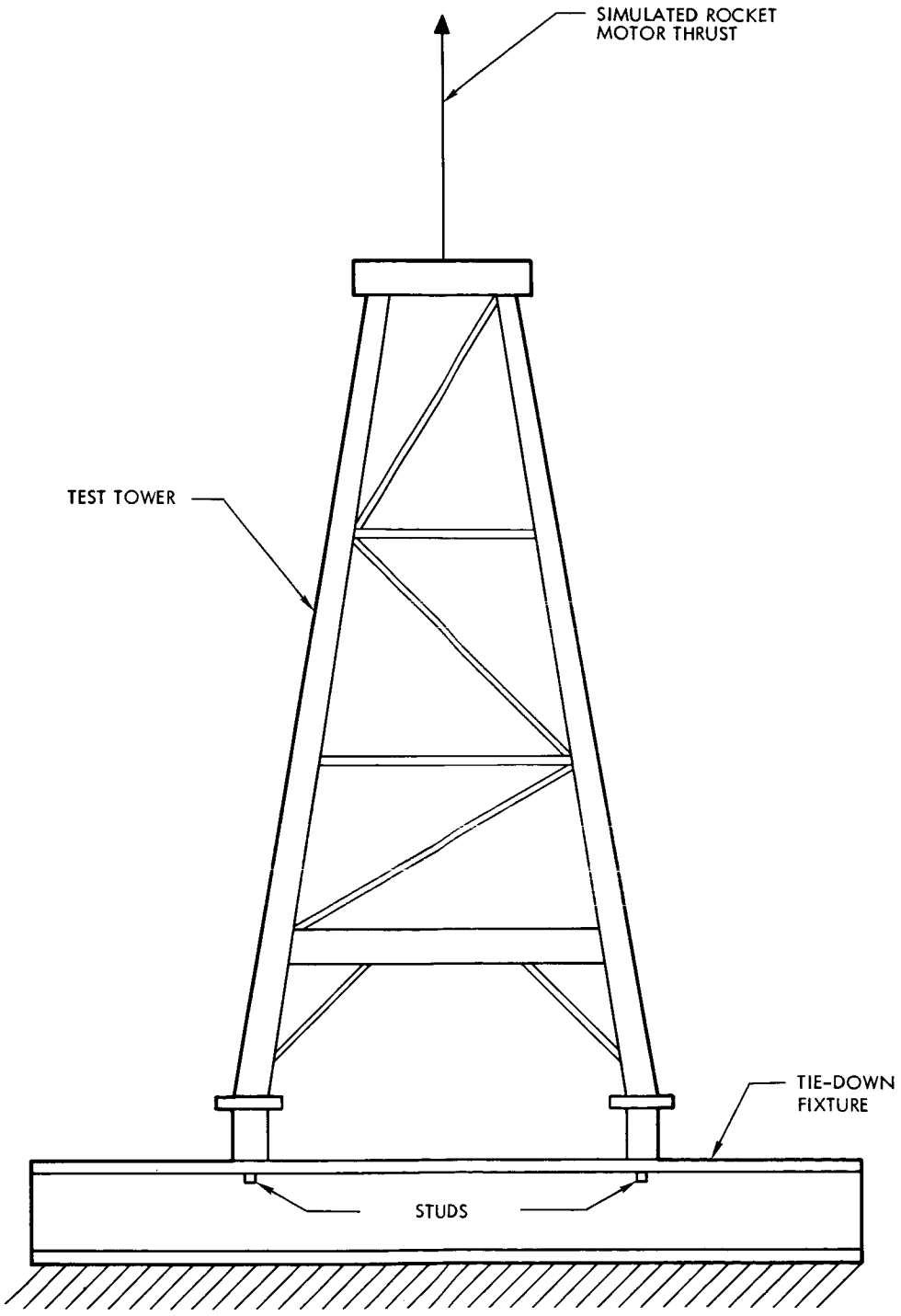



Figure 73. LES Test Setup

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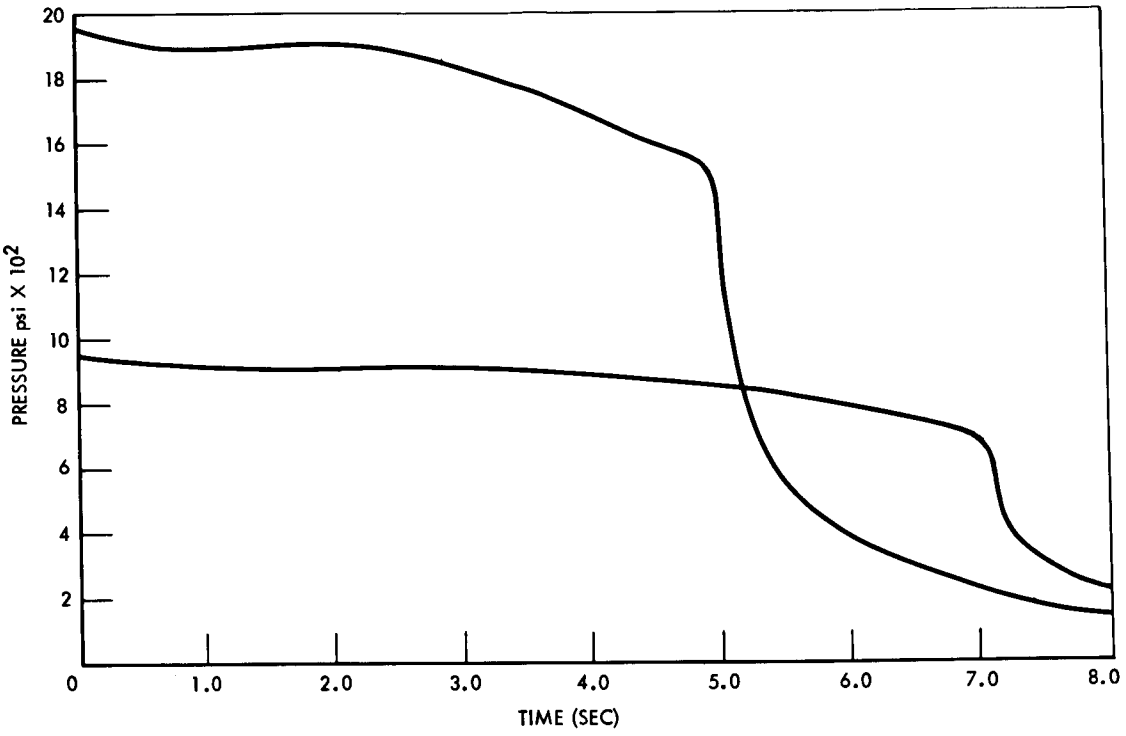


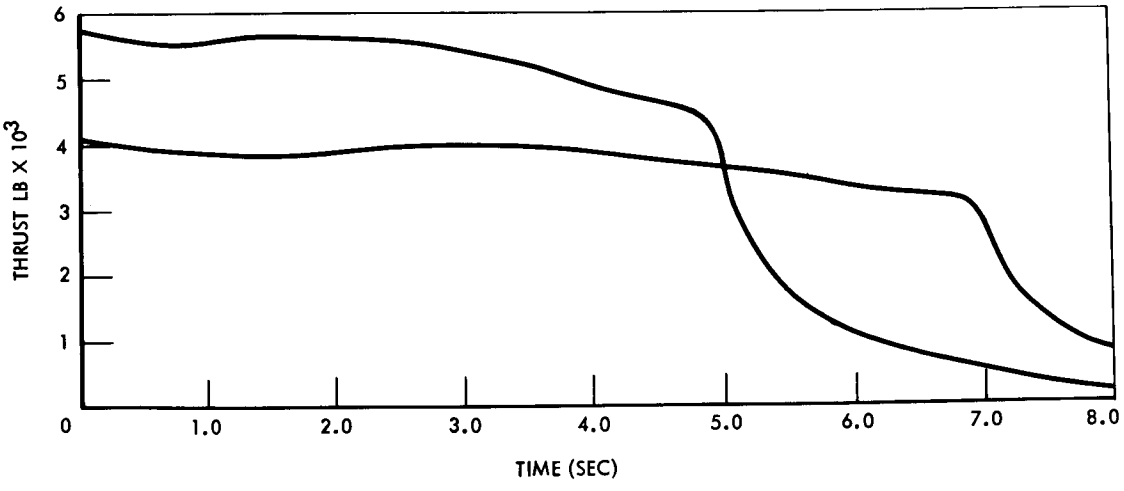


Figure 74. Theoretical Thrust and Pressure vs Time, Pitch Control Motor, 70 F, Sea Level, Maximum Impulse, and Minimum and Maximum Burning Times



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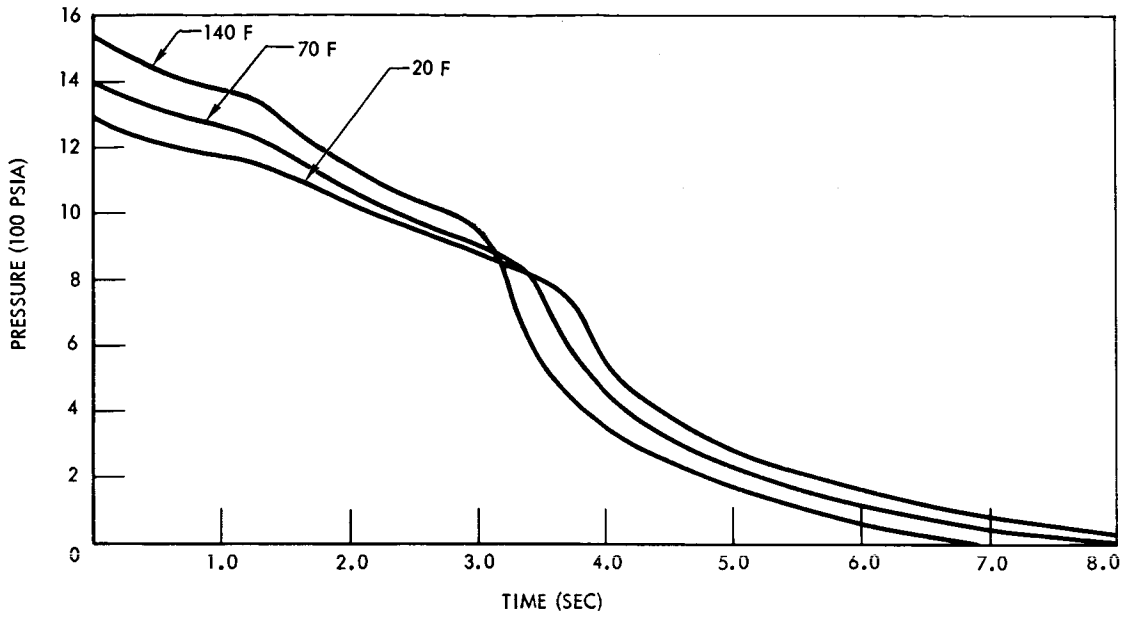


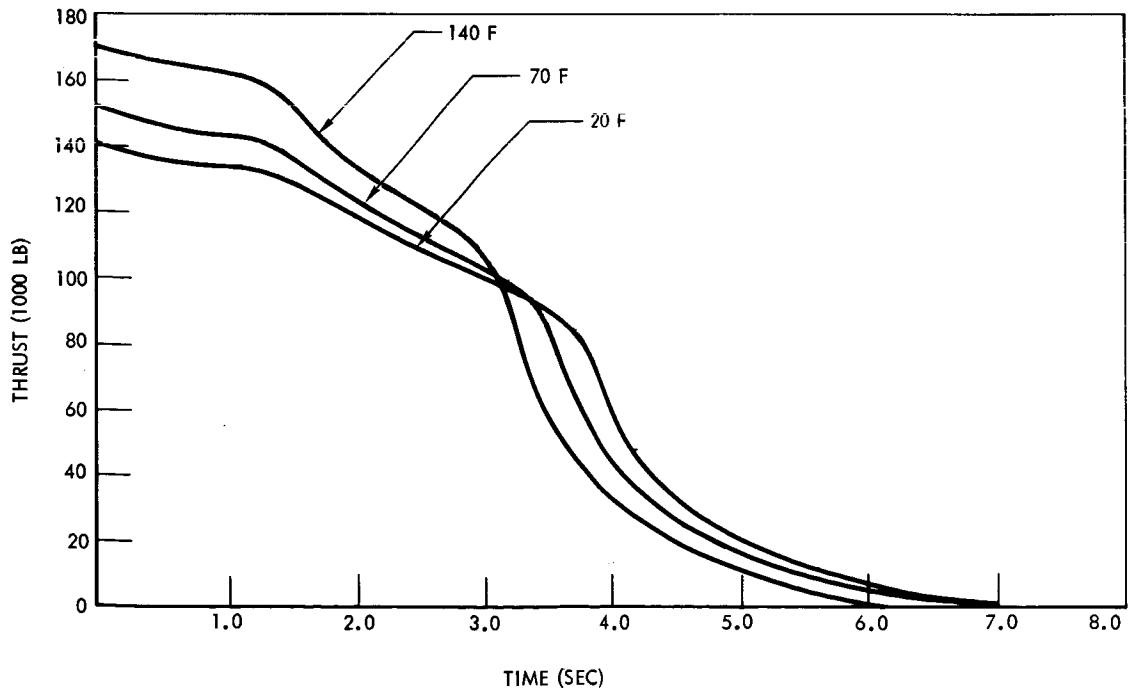


Figure 75. Theoretical Thrust and Pressure vs Time, Launch Escape Motor, and Sea Level



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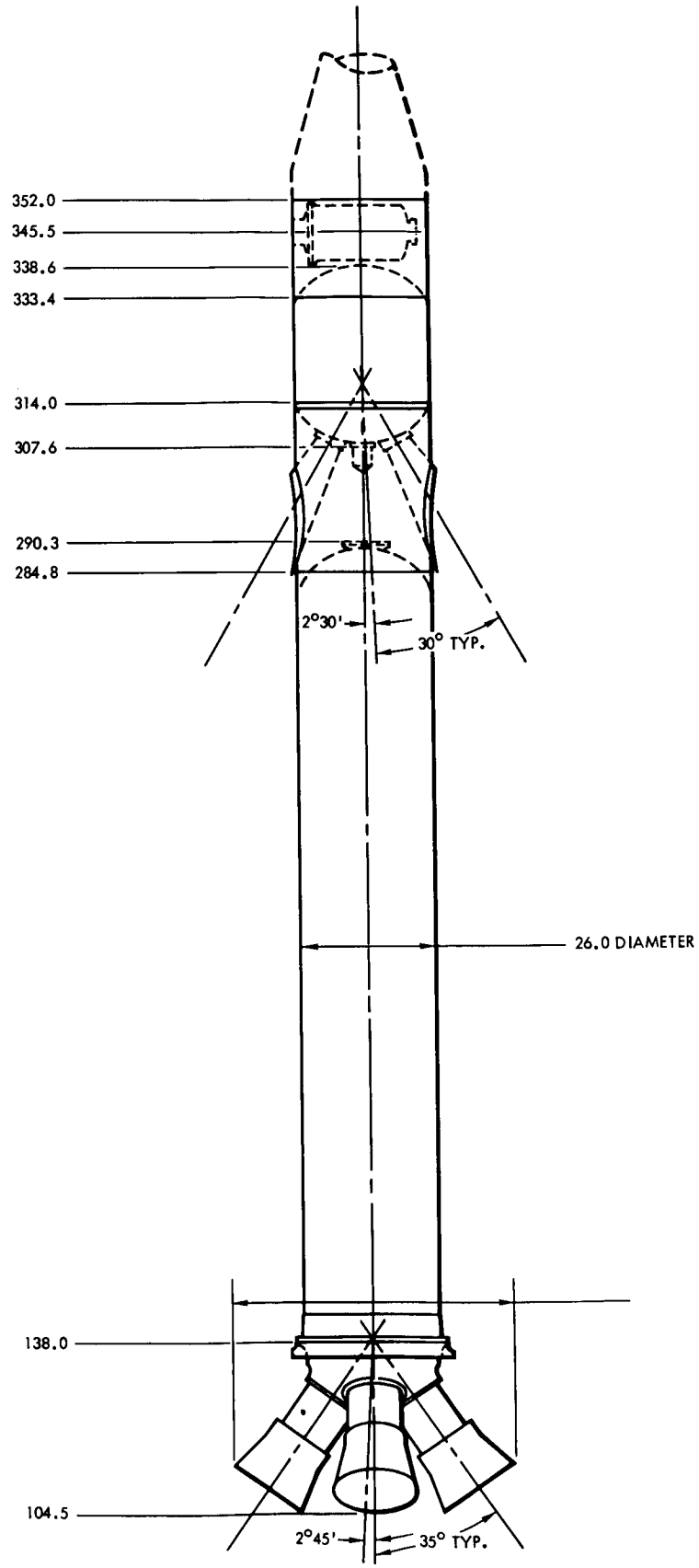


Figure 76. Apollo Launch Escape System Rocket Motors



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## Table 15. Launch Escape System Rocket Motors Preliminary Characteristics

| | Tower Jettison Motor | Launch Escape Motor | Pitch Control Motor |
|---|---|---|---|
| Length (overall) | 55 in. | 185 in. | 22 in. |
| Diameter | 26 in. | 26 in. | 9 in. |
| Grain design | 10-point star | 8-point star | 8-point star |
| Propellant | Polysulfide, ammonium Perchlorate | Polysulfide, ammonium Perchlorate | Polysulfide, ammonium Perchlorate |
| Weight (loaded) | 430 lb | 4,826 lb | 55 lb |
| Propellant weight | 204 lb | 3,170 lb | 17 lb |
| Weight (expended) | 222 lb | 1,717 lb | 38 lb |
| Nozzle no. and cant angle | 2 at 30 deg | 4 at 35 deg | 1 at 0 deg |
| Nozzle throat areas (each) | 8.65 $in.^2$ | 2 at 23.05 $in.^2$<br>1 at 26.12 $in.^2$<br>1 at 19.82 $in.^2$ | |
| Nozzle expansion half-angle | 10 deg | 17 deg 30 min. | |
| Nozzle area ratios | 5 to 11:1 | 10.9, 9.7, 12.7:1 | |
| Port-throat ratio | 26.5:1 | ≈1.7:1 | |
| Operating temperature range | 20 to 140 F | 20 to 140 F | 20 to 140 F |
| Storage temperature range | -15 to 160 F | -15 to 160 F | -15 to 160 F |
| Resultant thrust angle | 1 deg 0 min. | 2 deg 45 min. | 0 deg 0 min. |
| Total operating time | 1.25 sec | 7.88 sec | |
| Burn time | 1.0 sec | 3.45 sec | 0.5 to 0.7 sec |
| Action time | 1.2 sec | 5.90 sec | |
| Average thrust during burn time | 33,038 lb | 128,840 lb | 2,400 to 6,000 lb |
| Average thrust during action time | 30,900 lb | | |
| Average $P_c$ during burn time* | 1,519 $lb/in.^2$ | 1,130 $lb/in.^2$ | |
| Average $P_c$ during action time | 1,421 $lb/in.^2$ | 796 $lb/in.^2$ | |
| Total impulse during burn time | 33,038 lb-sec | 444,490 lb-sec | 1,200 to 3,000 lb-sec |
| Total impulse during action time | 37,128 lb-sec | | |
| Total impulse during total time | 37,129 lb-sec | 514,924 lb-sec | |
| Avg isp during burn time | 184 | | |
| Shutdown impulse | 4,091 lb-sec | | |
| Time to 90-percent thrust | 0.075 to 0.125 sec | 0.070 to 0.100 sec | 0.060 sec max. |
| C* | 4,690 ft/sec | 4,575 ft/sec | 4,575 ft/sec |
| Combustion temperature | 4,402 F | 4,600 F | 4,600 F |
| Propellant density | 0.0632 $lb/in.^3$ | 0.0618 $lb/in.^3$ | 0.0618 $lb/in.^3$ |
| Percent volumetric loading | 26 percent | | |
| $C_p/C_v$ | 1.25 | 1.23 | 1.23 |
| Burning rate $r_b$ = | $0.82\,(P_c/1,000)^{0.35}$ | $0.69_e(T-70)0.0081\,(P_c/1,000)^{0.46}$ | Same as launch escape motor |
| Temperature sensitivity, K(%/°F) | 0.125 | 0.15 | 0.15 |
| Igniter - redundant EBW | 2 AGX2008 squibs | 2 AGX2008 squibs | 2 AGX2008 squibs |

*Along res thrust vector , 70 F, sea level

[redacted]

# ENVIRONMENTAL CONTROL SUBSYSTEM

## TEMPERATURE CONTROLS

An analysis was completed of the dynamic performance of the suit temperature control, suit evaporator temperature control, cabin temperature control, and water-glycol temperature control. The temperature controls are similar in design with interchangeability being a major design objective. Shorting bars are being designed for the controls to permit the installation of any one of the controls into the various temperature control systems. A breadboard working model of the oxygen partial-pressure control was constructed and is being tested.

## COMPONENT ANALYSIS

The component weights of the environmental control system (ECS) package remained relatively unchanged. A weight reduction program is in progress for the carbon dioxide and the odor absorber. A reduction in weight may also be realized through the use of a wick-type separator replacing the sponge-type model. A significant weight reduction is expected for these components.

The requirements for the ECS checkout system were completed and approved.

A plastic coldplate was built for the visual observation of internal flows to check pressure-drop analyses for constant flow rates.

## CRYOGENIC STORAGE SYSTEM (CSS)

The change from a 7.0 psia oxygen-nitrogen atmosphere to a 5.0 psia 100-percent oxygen atmosphere has resulted in a deletion of the nitrogen system and the partial-pressure sensing and metering equipment. Elimination of the nitrogen system resulted in a substantial weight reduction. Substitution of total-pressure sensing-and metering equipment, an increase in oxygen tanks capacity, and other necessary modifications are being accomplished.

Because of the control problems associated with the water-glycol heat exchanger, electrical heaters will be used for the pressure-buildup system.

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A decision was made to supply all ECS a-c components with 400-cycle power from a master power system. Studies concerning frequency optimization have been discontinued.

The oxygen reentry storage (Figure 77) has been relocated to the left-hand equipment bay. The tanks will be serviced at a remote area and will be installed in a charged condition. The system will then be pressurized to 7500 psi at an ambient temperature. The integrated package will include tanks, fill valves, manual shut-off valves, relief valves, and regulators.

The environmental system equipment requirements have been established for the mock-ups, boilerplates, and airframes. These requirements are shown in Table 16.

## REDIRECTION TO LUNAR ORBITAL RENDEZVOUS MISSION

Effects of the lunar orbital rendezvous mission on the Apollo ECS were assessed, and a number of them have been identified. Other effects will be determined once the lunar excursion module configuration and mission have been established. Evidence indicates that the ECS cryogenic gas storage and waste management system will also be affected.

Additional cryogenic storage oxygen will be required during the time the lunar excursion module is mated to the command module. The quantity required will depend on the volume of the lunar excursion module, the design leakage rate, and the length of time it is mated to the command module.

Replacement of the air lock by a hatch will eliminate the 18 air lock pressurizations and result in a reduction of cryogenic gas required.

Because there will be only one man in the command module during the 2-to 4-day lunar orbit, the quantity of metabolic oxygen may be reduced for this mission. The quantity of lithium hydroxide will also be decreased because of lessened carbon dioxide production.

During the mating operation, glycol cooling may be supplied to the lunar excursion module through the interface by means of quick disconnects. In this case, the capacity of the Apollo ECS would be increased accordingly at a penalty in weight and volume requirements.

Air circulation may be required in the lunar excursion module when it is open to the command module. This circulation would require power to a fan in the lunar excursion module or an air duct through the interface.

Elimination of the lunar landing concept would reduce the size of the area allotted for the ECS space radiators. The deployable units would be replaced by fixed radiators.

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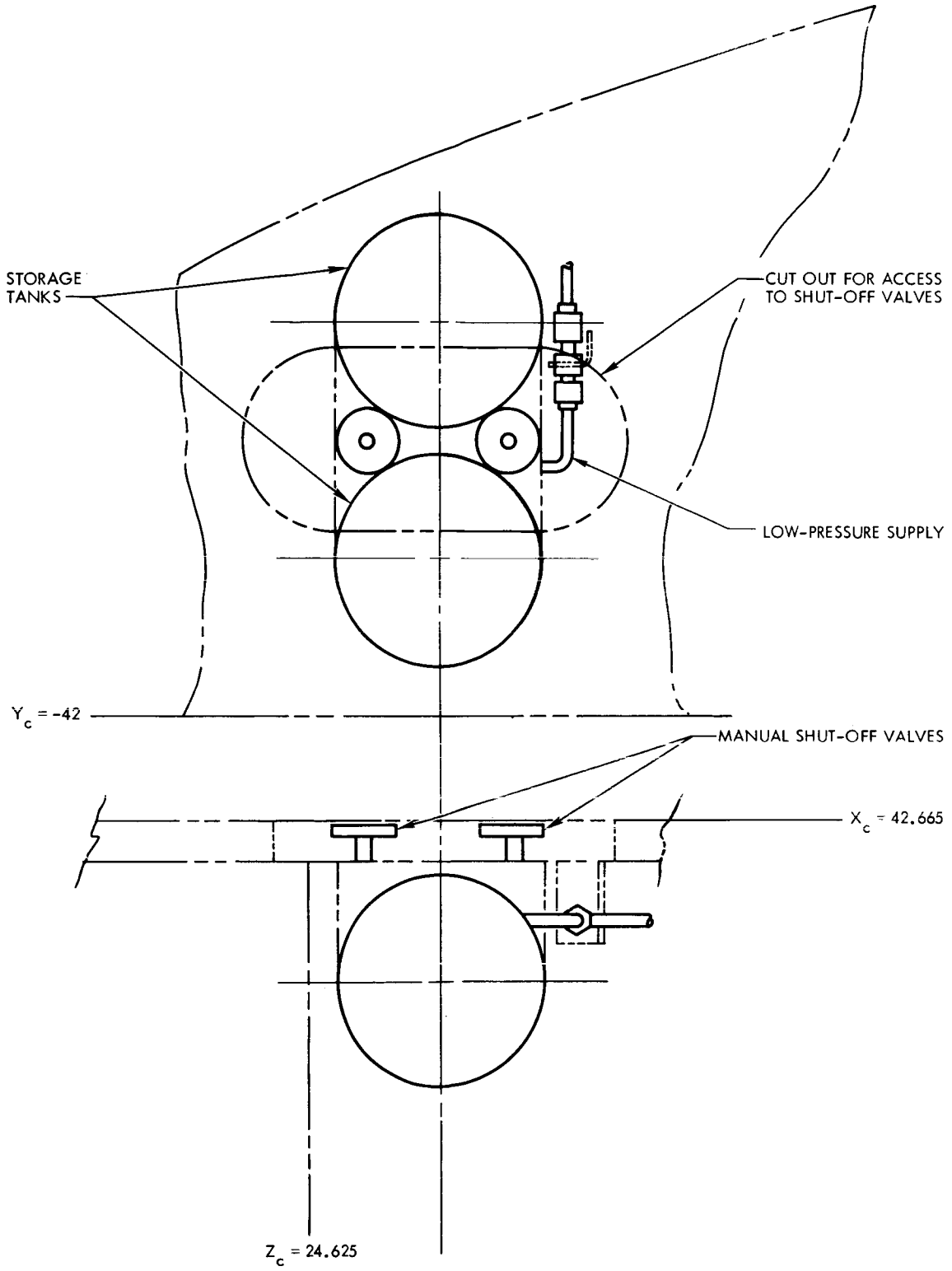


Figure 77. Reentry Oxygen Storage System



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# Table 16. ECS Utilization

| Structure No. | Environmental Control System | Cryogenic Storage System | Waste Management System | Space Radiators |
|---|---|---|---|---|
| **MOCKUP** | | | | |
| 2 | X | | X | |
| 3 | X | | X | |
| 5 | X | | | |
| 7 | X | X | | |
| 18 | X | X | X | |
| **BOILERPLATE** | | | | |
| 6 | (Special cooling) | | | |
| 8 | (Inlet and outlet valve, only) | | | |
| 12 | (Special cooling) | | | |
| 13 | (Special system) | | | |
| 15 | (Special system) | | | |
| 16 | (Spacecraft Glycol system) | | | |
| 18 | (Spacecraft Glycol system) | | | |
| 22 | (Special cooling) | | | |
| 23 | (Special cooling) | | | |
| **AIRFRAME** | | | | |
| 001 | X | X | X | X |
| 002 | (Spacecraft Glycol system) | | | |
| 006 | X | X | X | X |
| 008 | X | X | X | X |
| 009 and 010 | X | X | | X |
| 009A | (Service module, only) X | | | |
| 011 | X | X | X | X |
| 012 | X | X | X | X |

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Rework of the water management system will depend on supply quantities required from the command module to the lunar excursion module. Additional complications would arise if separate potable and cooling water supplies are necessary.

PRESSURE AND TEMPERATURE CONTROL

Due to the change to a 100-percent oxygen atmosphere, the cabin heat exchangers have been redesigned. (Figure 78). Weight will be saved as a result of the reduced power requirements for the suit compressors and the cabin fans.

Preliminary testing of the experimental unit of the regenerative heat exchanger revealed an excessive heat transfer during the by-pass condition across the heat side plates to the by-pass gas. This unit is being redesigned.

The inlet and outlet snorkels have been modified to a simplified valve configuration saving considerable weight.

ATMOSPHERIC CONTROL

A reduction in the oxygen consumption rate from 1.8 to 1.25 pounds per man per day would reduce lithium hydroxide requirements by 41 pounds with an effective volume reduction of 1.6 cubic feet and would eliminate the storage problem.

A package configuration of the total ECS has been completed for the major subsystems (Figure 79). This package can be readily removed from the vehicle for replacement or repair.

WATER MANAGEMENT

The fuel cell and water management interface is being defined in greater detail. Corrective measures are being applied where equipment malfunction can cause isolation or dumping of fuel cell water or the over-pressurization of water storage tanks (Figure 80).

The system schematic diagram has been revised to provide greater system versatility, more system redundancies, and a method to discharge excess water overboard. All accessible valves except check valves will be provided with manual override handles.

Manual shutoff valves have been added to provide in-flight system control for both normal and emergency procedures. Positive separation of Freon and potable water is assured through the use of a shutoff valve and a check valve as a minimum at each interface.

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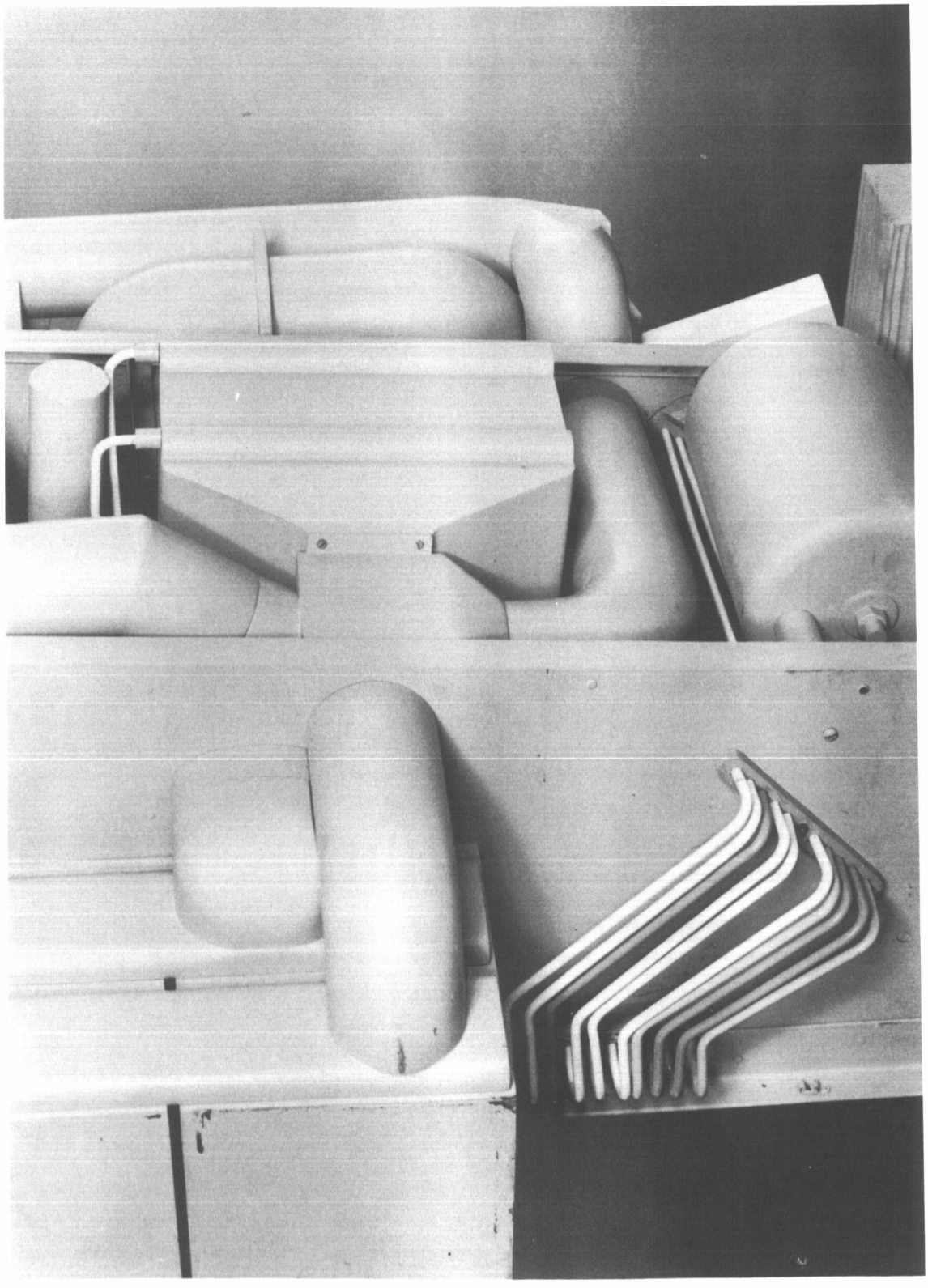

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Figure 78. Heat Exchanger Mounted in Escape Control System Package

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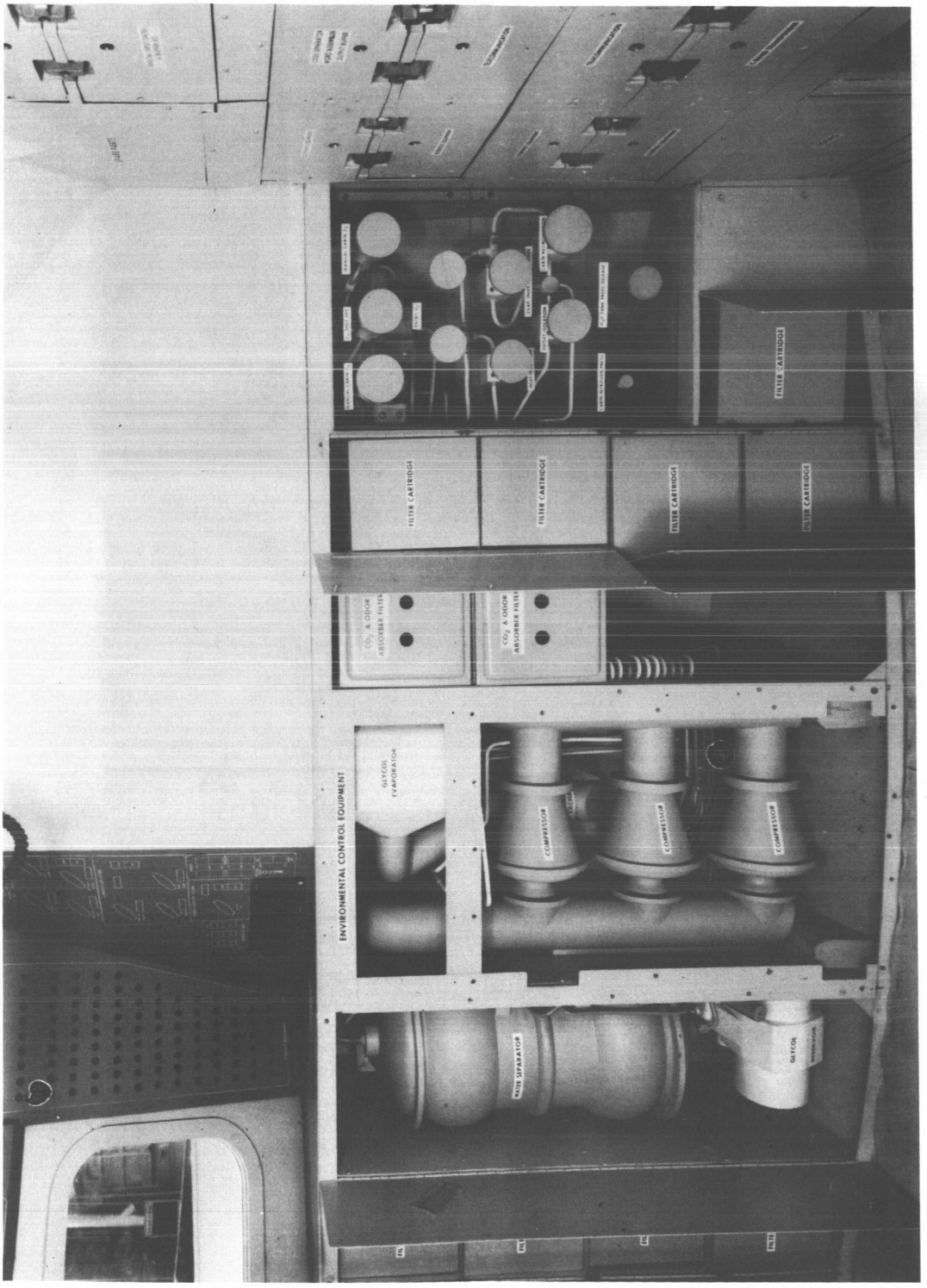


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Figure 79. Escape Control System Package Installation



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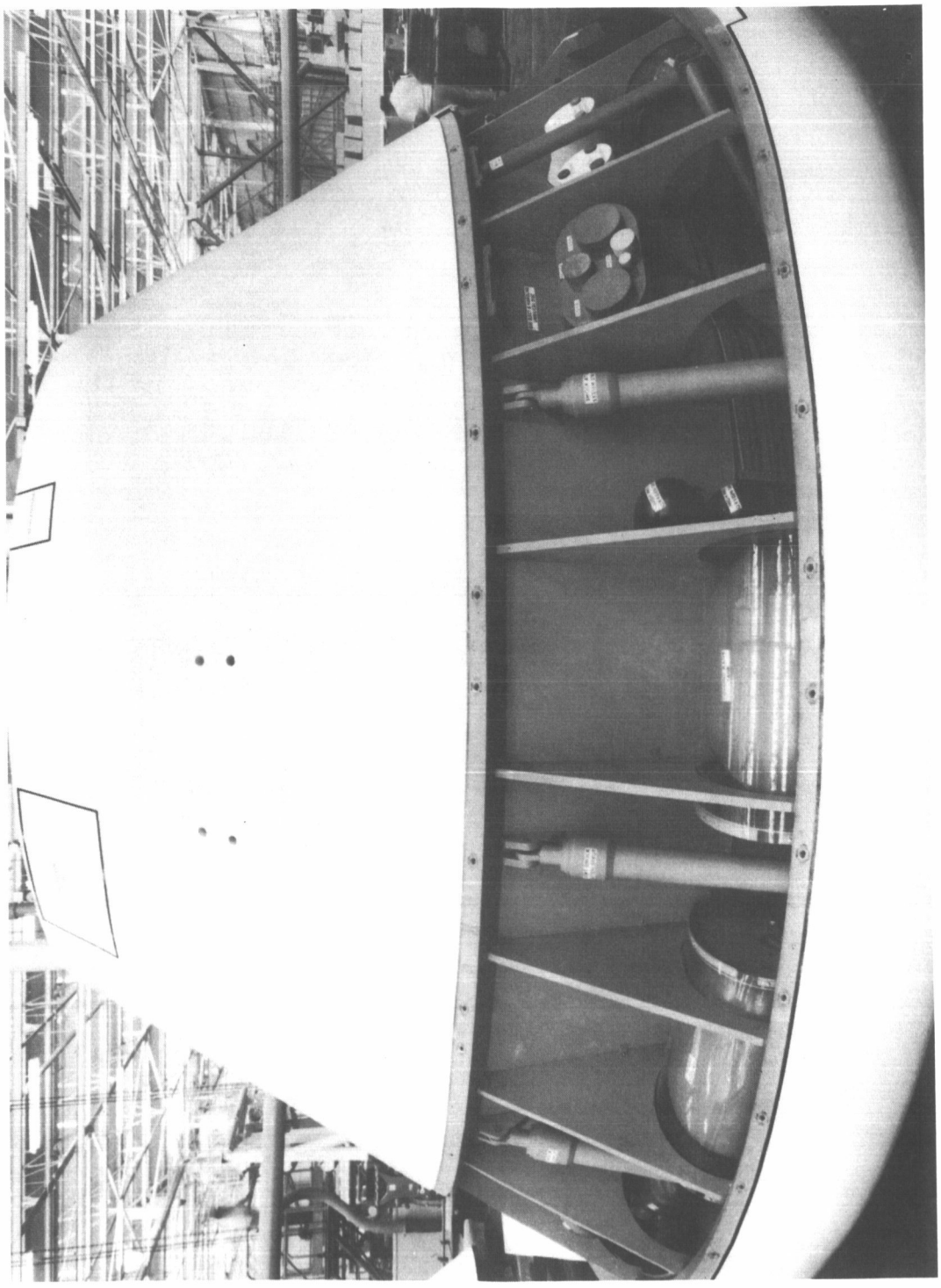

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Figure 80. Water Tanks in Aft Equipment Bay of Command Module



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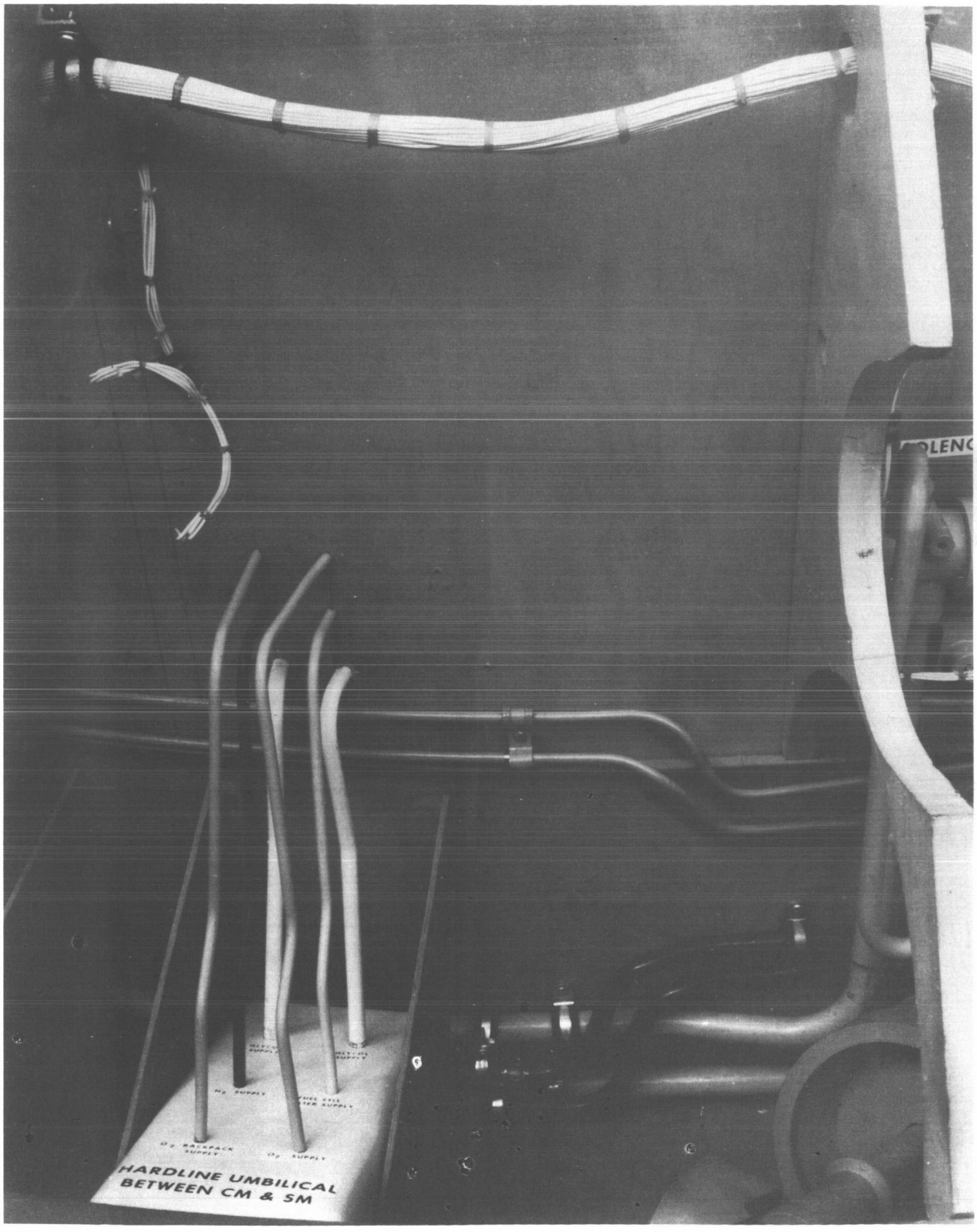


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Figure 81. Hardline Umbilicals

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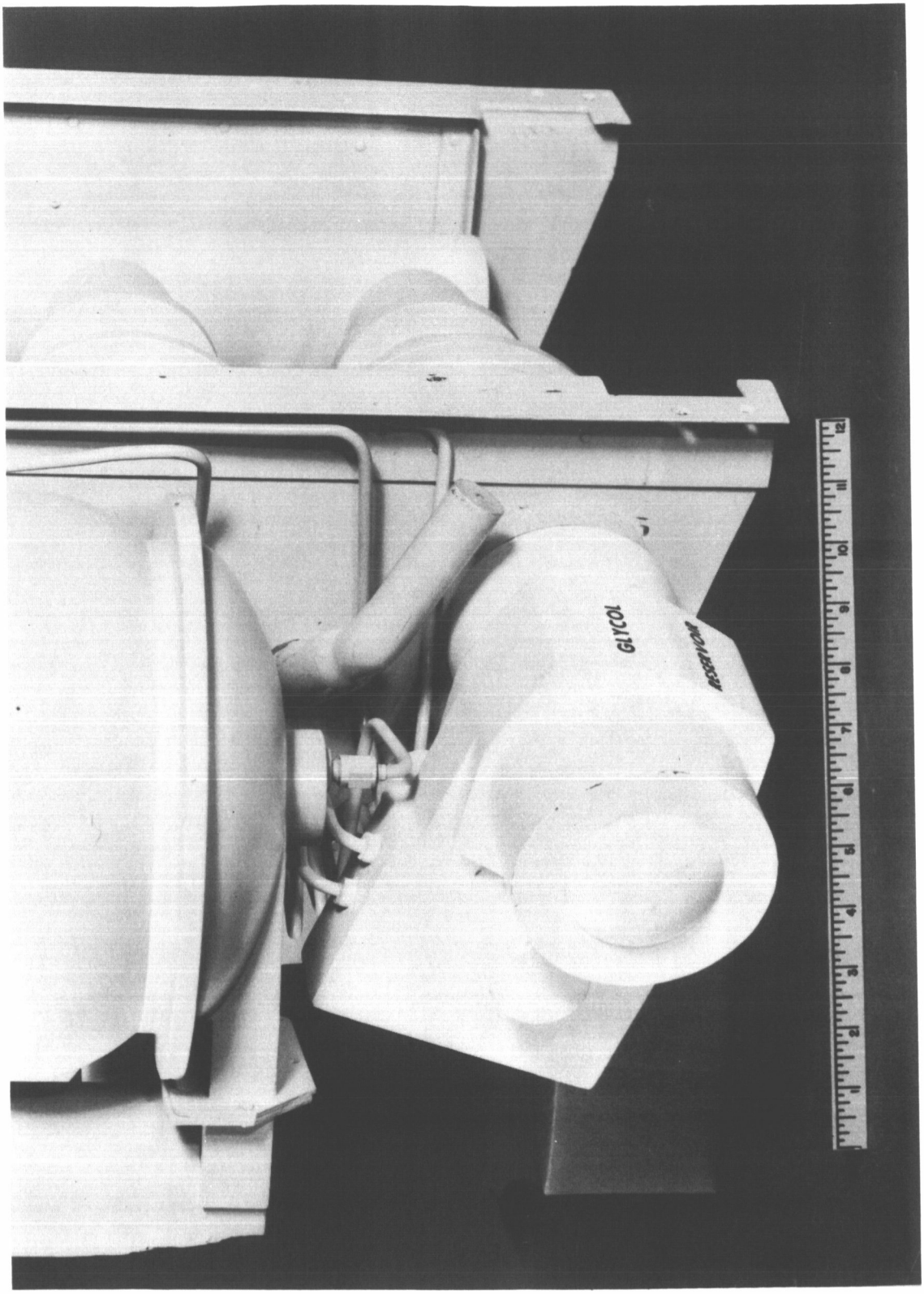


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Figure 82. Glycol Reservoir Mounted in Environmental Control System Package

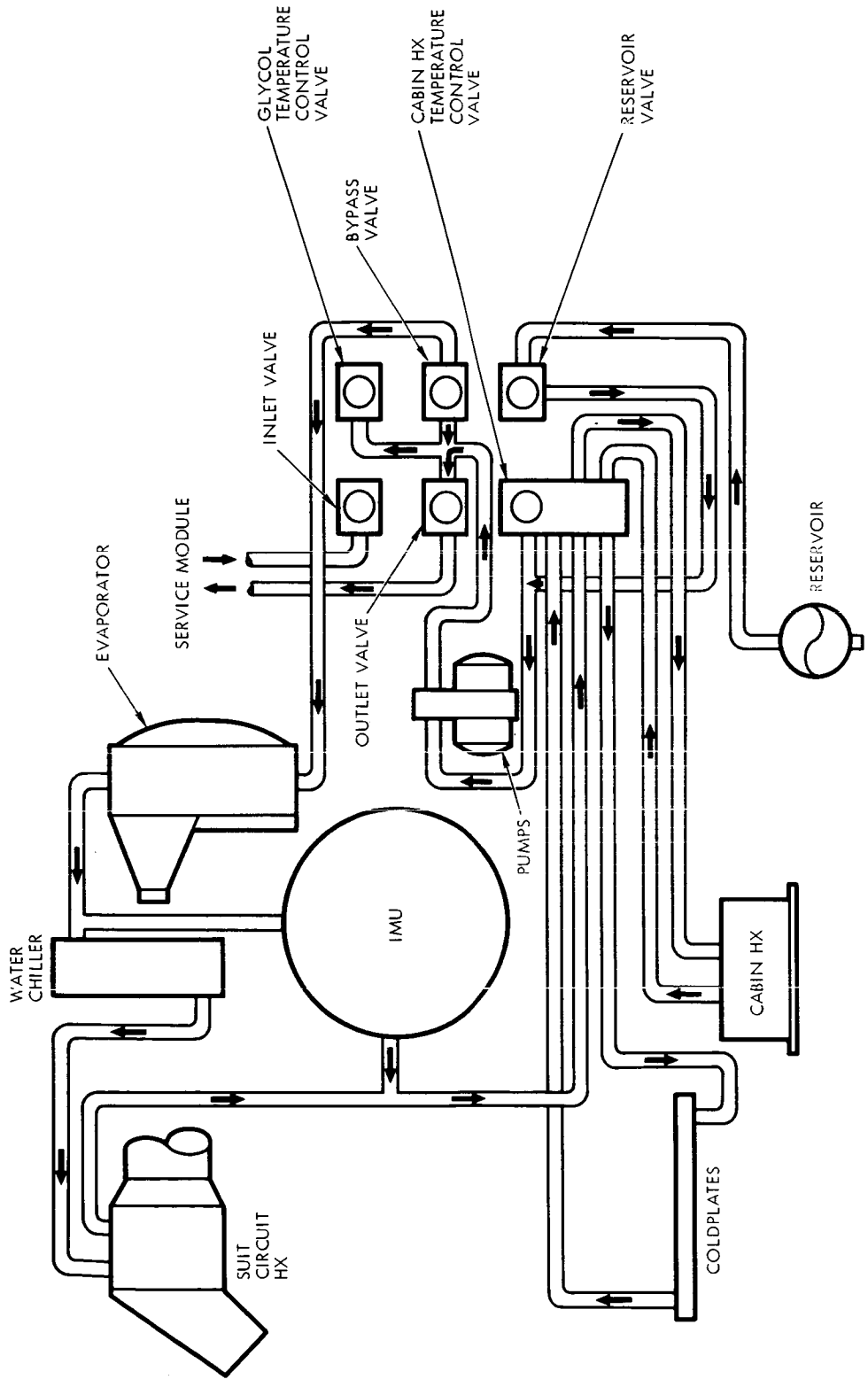


Figure 83. Water/Glycol System Command Module

The quality of water produced by the fuel cells is monitored by three separate Ph meters and one cumulative Ph meter located near the fuel-cell water outlets in the service module.

A study of radial, as opposed to longitudinal, tube passages in the radiator core indicated that this design has a reduced pressure drop and good rigidity characteristics, but questionable thermal performance.

It was decided to use a relatively simple but reliable device for measuring the amount of water in the potable and waste water tanks. The device consists of a flexible diaphragm capable of accepting a decrease in the volume of gas on the oxygen side of the bladder in the water tank. As this takes place, the increase in oxygen pressure can be noted, and the amount of water in the tank to be calculated.

A study is being performed to determine the feasibility of using a separate 3-pound-capacity hot-water reservoir to satisfy crew requirements. An electrical heater that will be used intermittently in conjunction with a bootstrap circuit that utilizes hot fuel-cell water is being considered as a means of retaining the required temperature.

COOLANT SYSTEM

A study was conducted to determine the feasibility of using an ablative plug within the coolant system command module-to-service module umbilical disconnect (Figure 81). Separation of the service module requires plugging the 3/8-inch holes in the heat shield to prevent burn-through.

A 35-inch prototype glycol reservoir is being fabricated. A 255-inch glycol reservoir (Figure 82), large enough to store one complete recharge of glycol for the entire ECS glycol system (Figure 83), has been incorporated into the latest ECS. This reservoir will be similar to the potable and waste water tanks that use an expulsion bladder actuated by oxygen pressure. The unit differs from the 35-inch reservoir in that the larger reservoir uses a spring to actuate the bladder.

An adhesive-bonded coldplate has been leak-tested and is now being instrumented for thermal tests. The first sample of a dip-brazed (1/8-inch thick) coldplate has been brazed and X-rayed to determine if the flow slots are clear of brazing flux.

A profile of radiator performance was completed for the lunar orbital mission. Evaporator water requirements were computed and were found to compare favorably with existing supply capability.

[redacted]

## WASTE MANAGEMENT SYSTEM

A valve was added to the urine ejection line in the aft equipment bay of the command module as a backup to the waste management selector valve (Figure 84) to prevent the loss of cabin oxygen if the selector valve leaked.

A study is being conducted concerning quantities and species of bacteria that may be collected by the vacuum cleaner.

The activated charcoal filter and check valve were removed from the fecal odor removal system. The waste management system, now coupled directly into the ECS, uses the ECS charcoal filter. One check valve was removed from the compartment ventilation system.

## TESTING

Testing continued on various catalysts in conjunction with the catalytic burner study test program. Due to the emphasis being placed on the weight-and-volume requirements of the Apollo ECS, carbon dioxide removal systems other than lithium hydroxide are being investigated. Feasibility testing is now in progress to determine the effect of superificial face velocity, moisture requirements, and bed length on the carbon dioxide absorption rate and bed utilization.

Evaluation tests are being conducted on the oxygen supply-demand pressure regulator, shutoff and metering valves, and line-mounted check valves.

Development tests are in progress on the oxygen pressure regulating valve assembly, the water-glycol multiple quick disconnect, and the cabin pressure relief valve (pilot valve only).

The reentry oxygen supply system is being repackaged for mounting within the pressurized area of the command module.

Development tests were conducted on a glycol pump driven by a wet motor. Results of these tests indicate that pump performance is very close to that predicted for the design. A dry motor-pump combination is being tested.

Tests of the water separator pump are under way. The current pump configuration uses oxygen-operational power. Redundancy will be accomplished by building two pumps in the same housing.

A vacuum chamber seal test was conducted using a viton "O" ring in a square groove. Results indicated a leakage rate less than the minimum detectable leak $1.26 \times 10^{-2}$ atmosphere cc's for a 19-day period. All tests conducted with a Viton "O" ring in a dove-tail groove produced unsatisfactory results.

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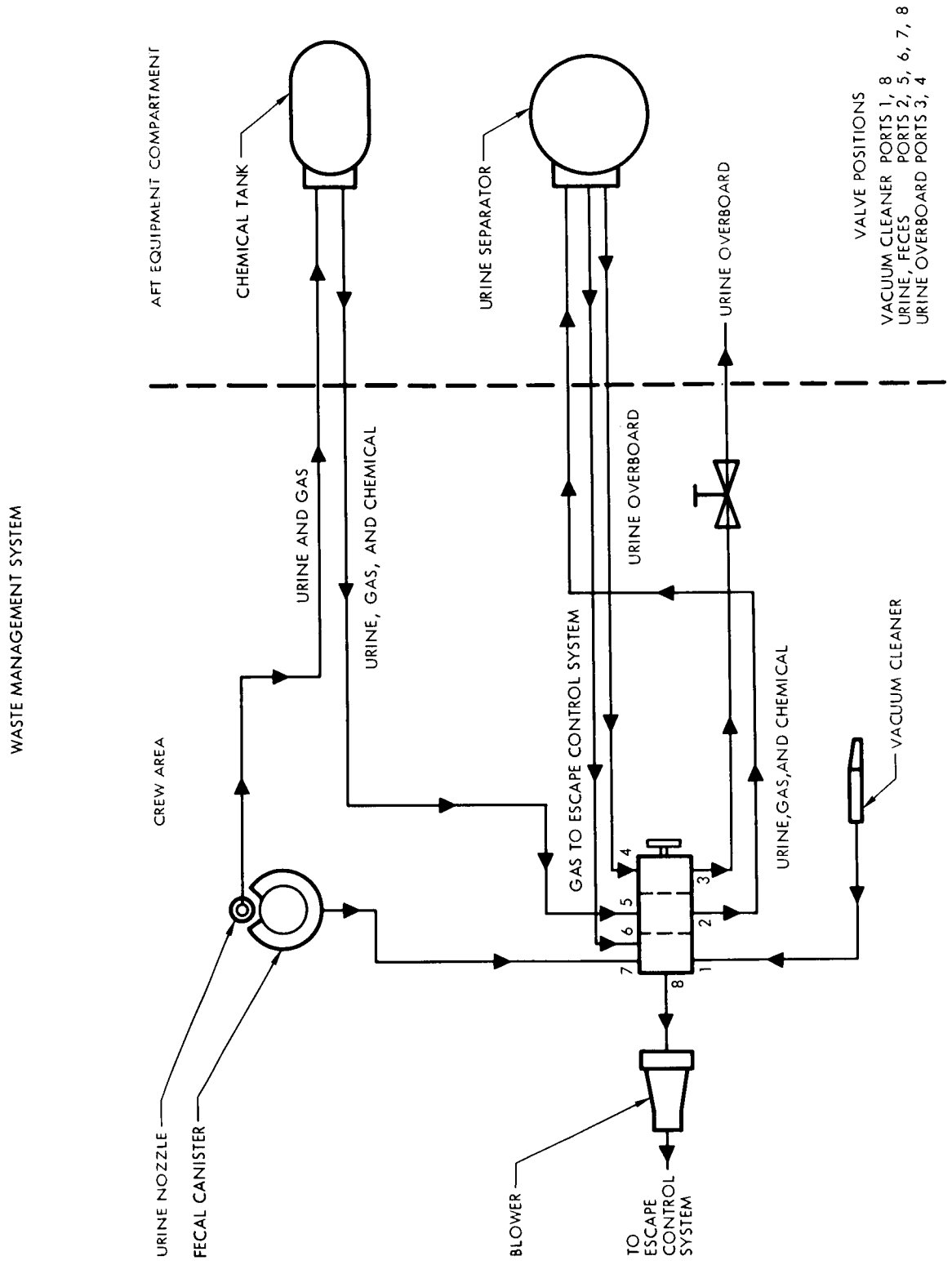


Figure 84. Waste Management System

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[redacted]

Preliminary design for a test setup of the ECS pressure suit subsystem was made, and the three-man metabolic simulator was designed. The metabolic simulator schematic was completed.

A test procedure has been issued for quick-disconnect couplings in boilerplates 6 and 20. This test will determine the static force versus allowable angles that will be required to disengage the couplings.

## COLDPLATE TESTS

Interface conductance tests were conducted on a 9-x 15-inch coldplate and a heater plate. In connection with these tests, two hot plates were designed and fabricated to provide uniform and nonuniform heat inputs of up to 2 watts per square inch to the coldplate. A 15-module simulated equipment package was instrumented and is now in use as a heat source (hotplate) for a series of interface conductance tests on the honeycomb sandwich coldplate.

The integrated ECS inflight instrumentation schematic was completed and released.

The ECS checkout concepts and support equipment requirements have been established for S&ID and AMR. Tentative checkout and countdown sequences have also been established.

The AMR vacuum chamber requirements were studied and have been established.

A wick-type water separator development unit is currently being tested in a breadboard test setup. A demand-type pump is being developed for use in conjunction with this unit. Development testing has indicated that the wick-type separator has distinct advantages over the water-type separator.

## BOILERPLATES AND MOCK-UPS

The design and detailing of boilerplate 6 is 90-percent complete. Boilerplates 12, 21, and 23 are 10-percent detailed, and boilerplates 13 and 15 schematics are complete.

The detail drawing of the telemetry coldplate is 100-percent complete and the detail drawing of the "C" band transponder is 50-percent complete. The insulation for boilerplates 6, 12, 21, 22, 23, 13 and 15, is 95-percent complete.

ECS layouts were prepared and have been printed for the 1/6-scale mock-up.

# EARTH LANDING SUBSYSTEM

A schematic of the complete sequence controller and parachute electrical system is shown in Figure 85.

Figure 86 is an operational schematic of a normal mission. Figure 87 is the operational schematic of an abort mission.

A system schematic of the forward compartment heat shield separation system is shown in Figure 88.

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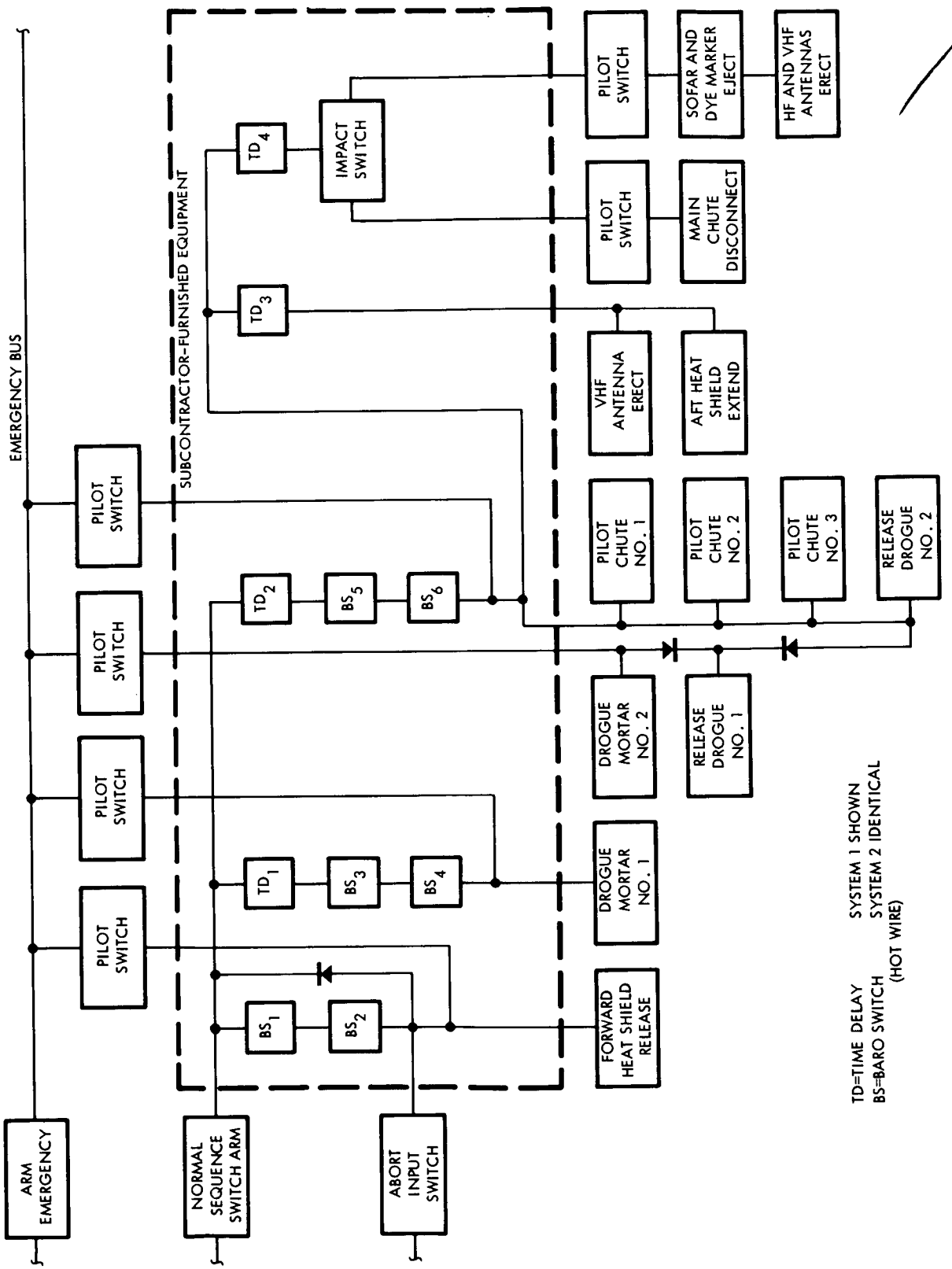


Figure 85. Earth Landing System Sequence Control Functional Block Diagram

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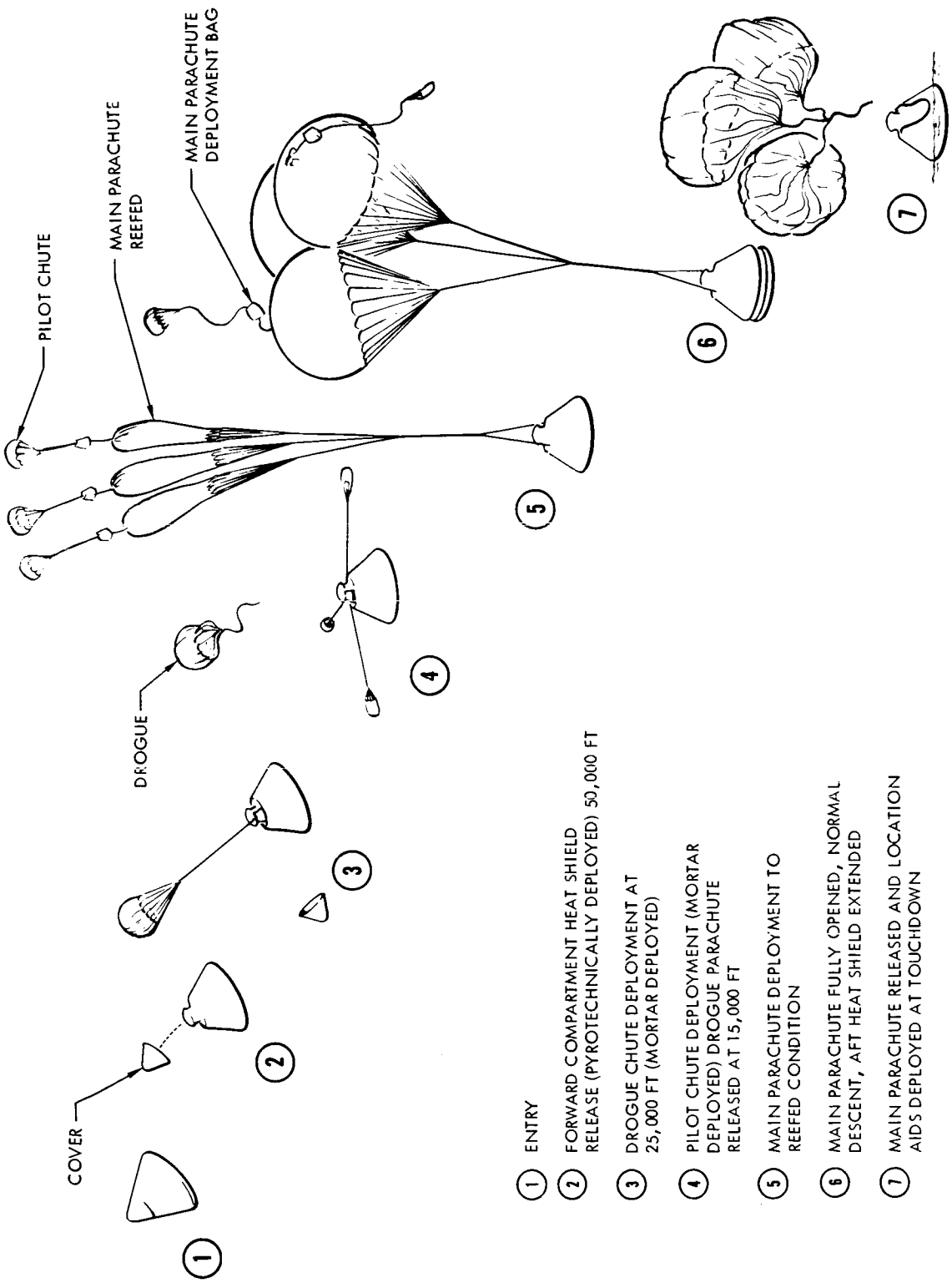


1. ENTRY
2. FORWARD COMPARTMENT HEAT SHIELD RELEASE (PYROTECHNICALLY DEPLOYED) 50,000 FT
3. DROGUE CHUTE DEPLOYMENT AT 25,000 FT (MORTAR DEPLOYED)
4. PILOT CHUTE DEPLOYMENT (MORTAR DEPLOYED) DROGUE PARACHUTE RELEASED AT 15,000 FT
5. MAIN PARACHUTE DEPLOYMENT TO REEFED CONDITION
6. MAIN PARACHUTE FULLY OPENED, NORMAL DESCENT, AFT HEAT SHIELD EXTENDED
7. MAIN PARACHUTE RELEASED AND LOCATION AIDS DEPLOYED AT TOUCHDOWN

Figure 86. Earth Landing System (Normal Landing)

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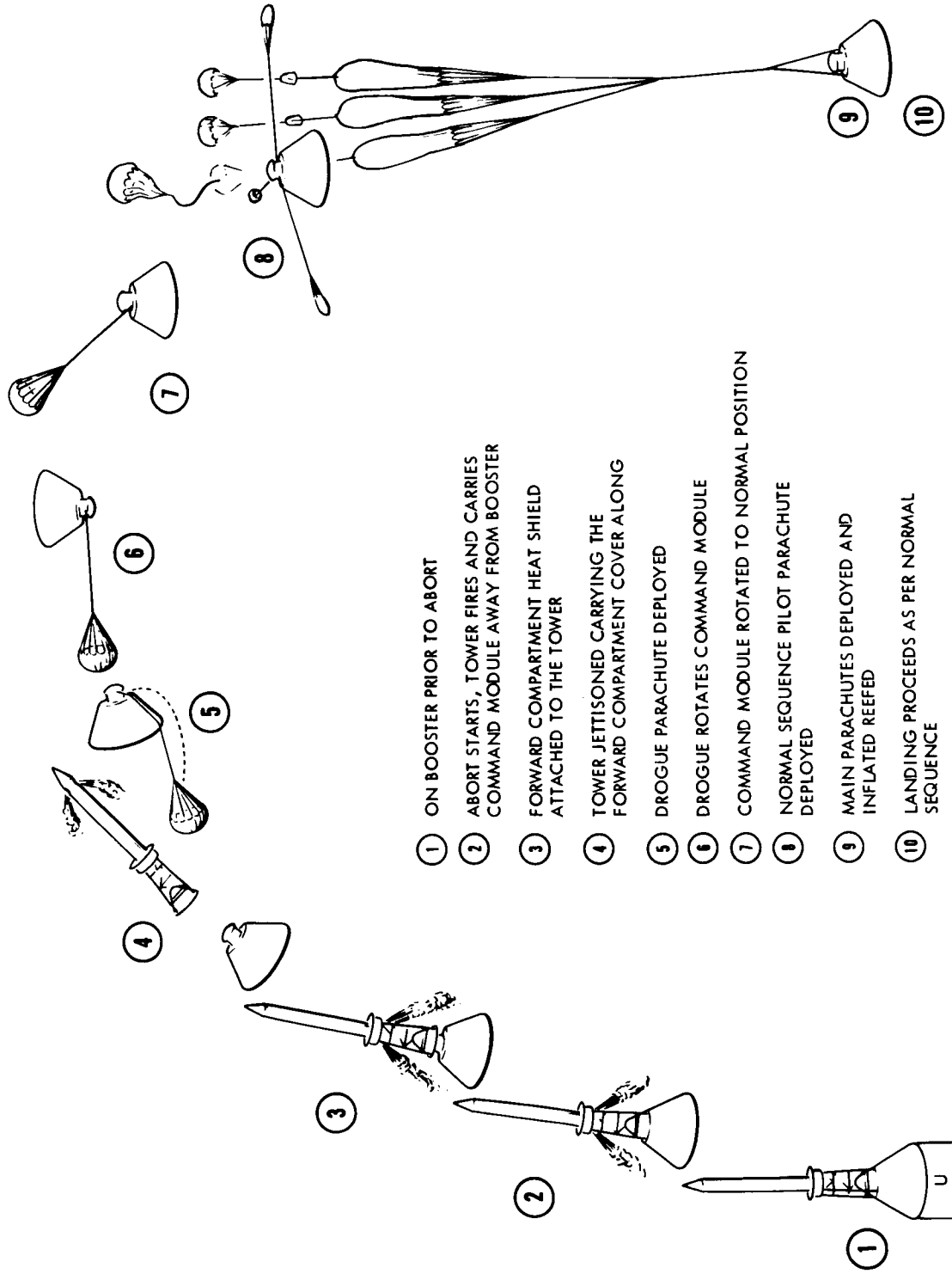


Figure 87. Earth Landing System (Abort Landing)

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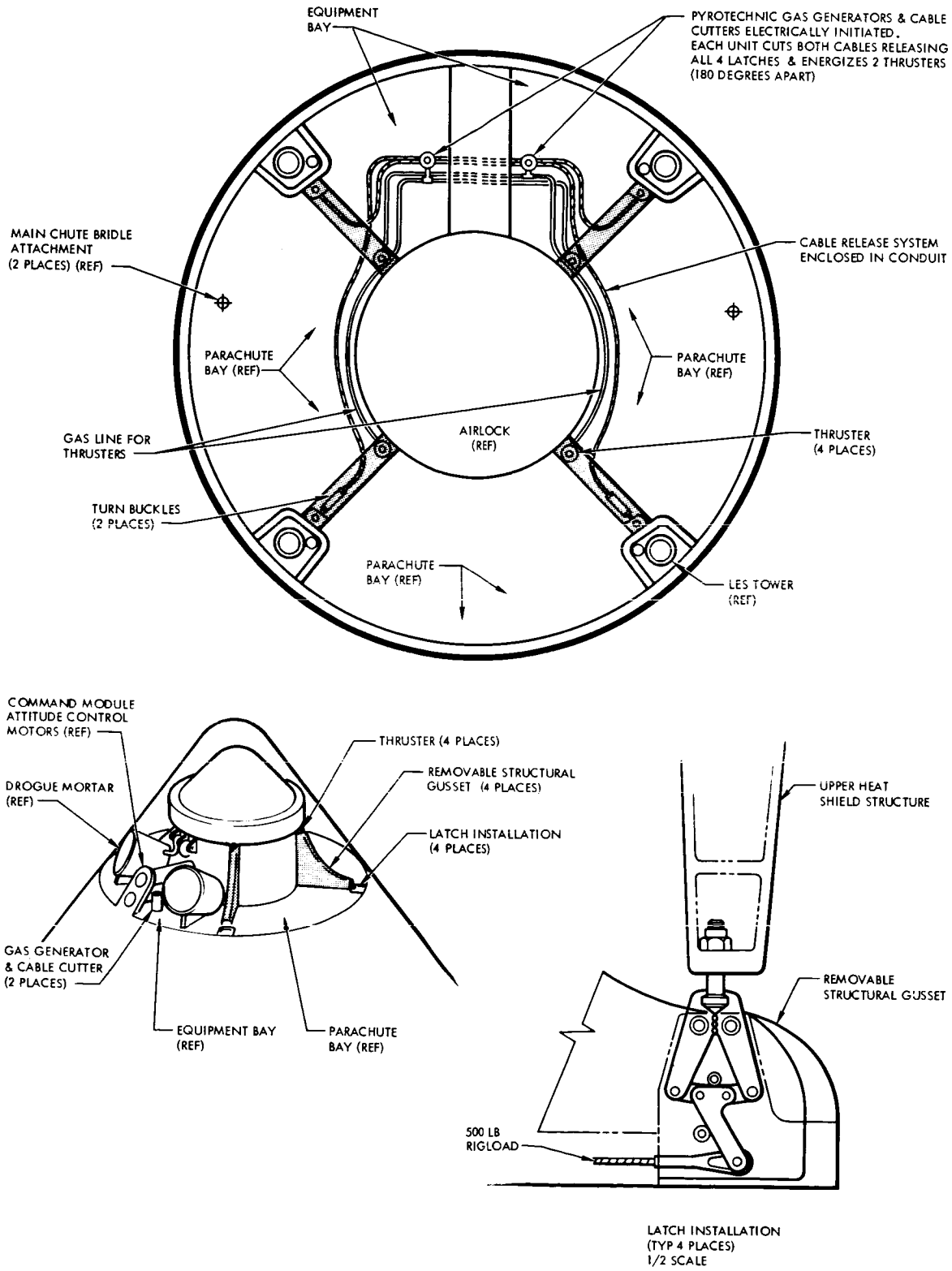


Figure 88. Forward Compartment Heat Shield Separation System

# COMMUNICATION SUBSYSTEM

## DSIF TRANSPONDER EQUIPMENT

A trade-off study was made to determine optimum location and configuration of the DSIF equipment. Preliminary results of the study indicate that savings in weight, complexity, and command module-to-service module interface problems would be obtained if a single DSIF transponder and power amplifier were located in the command module instead of two complete systems being located in the service module. Spares in excess of normal would be provided to ensure the reliability of this link.

In view of evaluation test results, the selection of an amplitron for the DSIF power amplifier is not feasible at this time.

## VHF EQUIPMENT

Reduction of the VHF equipment to one VHF-FM transmitter, one VHF-AM transceiver, and a VHF recovery beacon is being studied. Modular spares would be carried, and in-flight maintenance would replace equipment redundancy to reduce spacecraft weight.

## RADIO RECOVERY AIDS

Information on radio recovery aids received from NASA included a summary of Mercury tests performed on various types of beacons. These tests indicate that the ACR VHF beacon is compatible with both SARAH and ARA-25 type receivers. This beacon, along with other types of compatible beacon arrangements, is currently being evaluated in terms of input power requirements and range capabilities.

An investigation is being concluded to determine the optimum programming of VHF and HF radio recovery equipment that will reduce battery weight while minimizing recovery time.

Tests have been completed to determine the performance of the ARA-25 receiver when exposed to pulse-type signals of different repetition rates and pulse widths. The test results are being evaluated to determine a beacon pulse format that will be compatible with both ARA-25 and SARAH. The test results will also be compared with the NASA Mercury ACR beacon tests results.

PERSONAL COMMUNICATIONS

Present RF links and frequencies of the personal communication concept allow for integration and compatibility with the on-board 243 mc VHF transceiver.

The possible requirement of a crew member leaving the spacecraft prior to translunar ejection to align the lunar excursion module to the spacecraft has not been defined. If this becomes a requirement, the spacecraft will require a VHF-FM 450 mc receiver. At present, the requirement to receive the life support data exists only in lunar excursion module for relay to GOSS. An alternate concept under study is to delete the 450 mc FM link relay life support data on the 243 mc AM link by sharing it with voice communications.

UNIFIED COMMUNICATIONS STUDY

The possibility of achieving a major reduction in telecommunications system weight by the use of the DSIF equipment for near-earth communications and ranging is being studied. In addition to the weight trade-off studies fundamental to such a study, detailed analyses are being made considering the antenna coverage problem associated with the single parabolic antenna proposed for the DSIF transponder, the effect on the communications system reliability, and the most feasible scheduling of spacecraft equipment delivery.

Preliminary analysis of pseudorandom noise ranging capabilities for use in near-earth operations indicates the accuracy requirements can be met.

MODULATION TECHNIQUE STUDY

An analytic study of a number of modulation/reception techniques was made to enable selection of optimum techniques for use in the Apollo spacecraft-to-GOSS cislunar communication link. The report compares analog and digital modulation techniques for television, telemetry, and voice and includes a detailed summary of link design. The modulation/reception techniques studied are as follows:

1. Frequency Modulation

   With 2nd order phase-lock loop demodulator

   With an FM-feedback demodulator

   With a conventional FM receiver

2. Pulse Code Modulation

   Straight biphase modulation of the carrier with optimal product demodulation

   Regular simplex coding, optimal product demodulation of biphase modulated carrier

   Frequency shift keying of the carrier, coherent detection by modulation tracking phase-lock loop

3. Delta Modulation

   Biphase carrier modulation, detection without decision element

   Biphase carrier modulation, decision element detection

4. Amplitude Modulation

   Double sideband suppressed carrier

   Single sideband suppressed carrier

5. Phase Modulation

   Modulation restrictive phase-lock loop demodulation

An evaluation of the theoretical capabilities and practical limitations of the studied techniques indicated that frequency modulation is the most efficient modulation technique for a single channel of nonredundant information. To achieve this efficiency, a modulation tracking phase-lock loop is required as a demodulator. Until recently, demodulators of this type have been restricted in capability to relatively narrowband information. A recent development has extended the bandwidth capability of such receivers to information bandwidths in excess of 6 mc, more than adequate for the widest bandwidth signals generated by Apollo.

Digital techniques, although inferior to FM in the transmission of nonredundant information, provide more convenient and efficient methods of bandwidth reduction for the transmission of such redundant information as television.

To evaluate the relative merits of the two techniques, two televison studies were performed. Detailed documentation of these studies will be presented during the next report period. The analog system was selected for Apollo TV after engineering evaluation of all factors involved.

[redacted]

## PCM TELEMETRY INPUT REQUIREMENTS

Table 17 indicates the number of data channels for each of five basic PCM T/M sampling rates. Each data sample is coded to an eight-bit binary number with the exceptions that event functions (on-off) are represented by one bit, and certain digital data samples require multiples of eight-bit groups to represent one sample. These exceptions are noted under the "Bits per Word" column in Table 17.

The column under "Input Range" in Table 17 shows zero to full-scale levels for analog inputs and positive logic levels for digital inputs.

The column labeled "Total Samples/Sec" indicates the number of samples, normalized to eight bits, for each sampling rate for analog, event, and digital measurements. The total PCM capacity is 8000 eight-bit samples each second or a bit rate of 64,000 bits per second. The chart shows a present requirement of 7580 samples per second indicating capability for expansion.

## PCM SYNCHRONIZATION STUDY

Two methods considered were same sync code in each frame identification and same sync code in each frame inverted in a unique pattern. If the former method is used, the sync code will be alternatively inverted or reflected.

Four sync codes considered were (1) combinations of barker code 11-bit barker + 11-bit barker complement, (2) pseudorandom codes (simulate random data), (3) minimum probability codes (minimum probability of false sync indication) and (4) multiaperture codes (can detect a slip of one or more bits in synchronization).

## APOLLO TV STUDY SUMMARY

### Picture Evaluation

Scenes of live pictures and geometric patterns were photographed by a still TV camera then video-taped and transmitted via a microwave system.

### Conclusions

Digital TV systems are not sufficiently developed at this time, and there is a need for further investigation into scan conversion techniques. Suitable system parameters that are acceptable for Apollo TV requirements are 278 lines, 10 FPS, and 400 KC BW. Digital TV using PCM (4 bits) and Roberts modulation produces good quality pictures, but digital TV is less reliable than analog TV. A lunar-earth TV link should be analog TV.

Table 17. PCM T/M Input Requirements

| Quantity | Sampling Rate/Sec | Bits per Word | Type | Input Range | Total Samples*/Sec |
|---|---|---|---|---|---|
| 2 | 500 | 8 | Analog | 0 to 5 volts | 1000 |
| 18 | 100 | 8 | Analog | 0 to 5 volts | 1800 |
| 53 | 50 | 8 | Analog | 0 to 5 volts | 2650 |
| 125 | 10 | 8 | Analog | 0 to 5 volts | 1250 |
| 175 | 1 | 8 | Analog | 0 to 5 volts | 175 |
| 100 | 1 | 8 | Analog | 0 to 250 millivolts | 100 |
| 48 | 10 | 1 | Event | 0 or 4.5 volts | 60 |
| 80 | 1 | 1 | Event | 0 or 4.5 volts | 10 |
| 2 | 100 | 8 | Digital | 0 or 4.5 volts | 200 |
| 2 | 10 | 32 | Digital | 0 or 4.5 volts | 80 |
| 2 | 10 | 16 | Digital | 0 or 4.5 volts | 40 |
| 15 | 1 | 8 | Digital | 0 or 4.5 volts | 15 |
| 1 | 50 | 32 | Sync | 0 or 4.5 volts | 200 |
| | | | | Total | 7580 |
| | | | | Miscellaneous | 420 |
| | | | | Grand Total | 8000 |

* 1 Sample = 8 Bits

# NAVIGATION AND GUIDANCE SUBSYSTEM

## PRIMARY GUIDANCE

The entry guidance scheme was obtained from MIT. It is currently being evaluated in terms of inertial measurement unit (IMU) and Apollo guidance computer (AGC) requirements. Evaluation shows that the MIT scheme requires h (altitude rate) information. The error from the IMU and AGC is divergent.

A study is under way, with a computer simulation of the MIT system, to determine the sampling rate required to converge on the landing site. Closed-loop guidance error analysis is being conducted with the computer simulation.

## SURVIVAL ENTRY GUIDANCE

Several studies are under way on a digital computer simulation, including range curves to monitor the primary guidance system and to establish a roll program for down-range control and cross-range control.

The range-sensitivity coefficient (error analysis) is being determined for variations in time of roll maneuver, air density, and aerodynamic coefficients.

Survival boundaries for maximum g, uncontrolled skip-out, and heat load are being determined.

Any modifications to these boundaries due to variations in air density and aerodynamics are also being determined by computer simulation.

Mercury flight test data are being examined to determine the minimum g level for starting the clock.

The earth-orbit mission entry-guidance analysis study was completed for the rolling open-loop, lifting open-loop, and lifting closed-loop methods of entry.

## APOLLO BACK-UP NAVIGATION AND GUIDANCE (ASCENT PHASE)

A report entitled "Preliminary Considerations for Apollo Back-up Navigation and Guidance," was completed. It describes alternate primary

[redacted]

system philosophy incorporating the DSIF, orbital tracking, ascent tracking data for guidance, and extensive use of ground computation.

## DAMPING OF ORBITAL UNCERTAINTIES

Navigation requirements for lunar/earth orbit are being determined. Results indicate that velocity error is minimized by the resetting of position every 81 degrees along the orbit. The mechanization of the technique is based on position fixes obtained by use of the scanning telescope. Relations were developed for coordinate transformations, to be used with the scanning telescope. Work done in this study includes checkpoint damping for lunar or earth orbital navigation and extension of checkpoint damping techniques for lunar or earth orbital navigation.

## LUNAR AND EARTH ORBITAL NAVIGATION TECHNIQUES AND REQUIREMENTS

A navigation and guidance requirements document will be published containing the following material:

Introduction to statistical orbit determination techniques
Circular orbit error partials for lunar and earth orbits
Effect of air density uncertainty on earth orbital uncertainties
Comparison of data filtering techniques
Checkpoint damping techniques
Earth and lunar orbital operational procedures

In the area of data filtering requirements, computer simulation of Kolman methods, least squares, and maximum likelihood estimates on data filtering are being analyzed. Comparisons will be made with the checkpoint damping techniques.

## BACK-UP MIDCOURSE GUIDANCE STUDY

This investigation served to develop and program formulas to determine an approximate orbit for the midcourse lunar mission. The effects of photographic errors, measurement errors, and parameter uncertainties on computed velocities, positions, and entry conditions were determined.

## TWO-DIMENSIONAL RENDEZVOUS GUIDANCE SCHEME

A nominal free-fall trajectory leading to rendezvous has been computed, based on the ferry and target equations of motion and a specific time-to-go. The ferry is forced onto this nominal trajectory by engine thrust. When the ferry has achieved correct velocity, engine thrust is cut off. Upon reaching

the intended target point on the free-fall ellipse, a position match is produced. The choice of a second target point and time-to-go results in a velocity and positon match, allowing docking procedure to begin.

The Gauss method is used to compute a nominal trajectory on board, using two specified positions and time-of-coast between two positions. A velocity-to-be-gained vector is computed. The engine is then fired and the thrust vector aligned with the velocity-to-be-gained vector. When the latter is driven to zero, the engine is shut down.

This guidance scheme is being mechanized on the IBM 7090 digital computer.

A general functional block diagram of the combined guidance and control system is shown in Figure 89.

## LUNAR OPERATIONS

Factors influencing the choice of a circular lunar parking-orbit altitude are being analyzed. A 7090 program has been written and preliminary results have been tabulated.

The philosophy associated with Apollo back-up guidance requirements was investigated. The need for an alternate primary system was studied in addition to the need for integrity determination loops.

## RADAR

An optical beacon, located on the spacecraft, will be used for assistance in acquisition and angle tracking. The work that relates the beacon intensity, required as a function of star magnitude and range, has been done.

As a back-up mode, the visibility of the spacecraft (due to reflected light) was studied. The conclusions were that the spacecraft will be visible to the unaided eye for part of the orbit, depending upon the relation of the sun, viewer, and spacecraft.

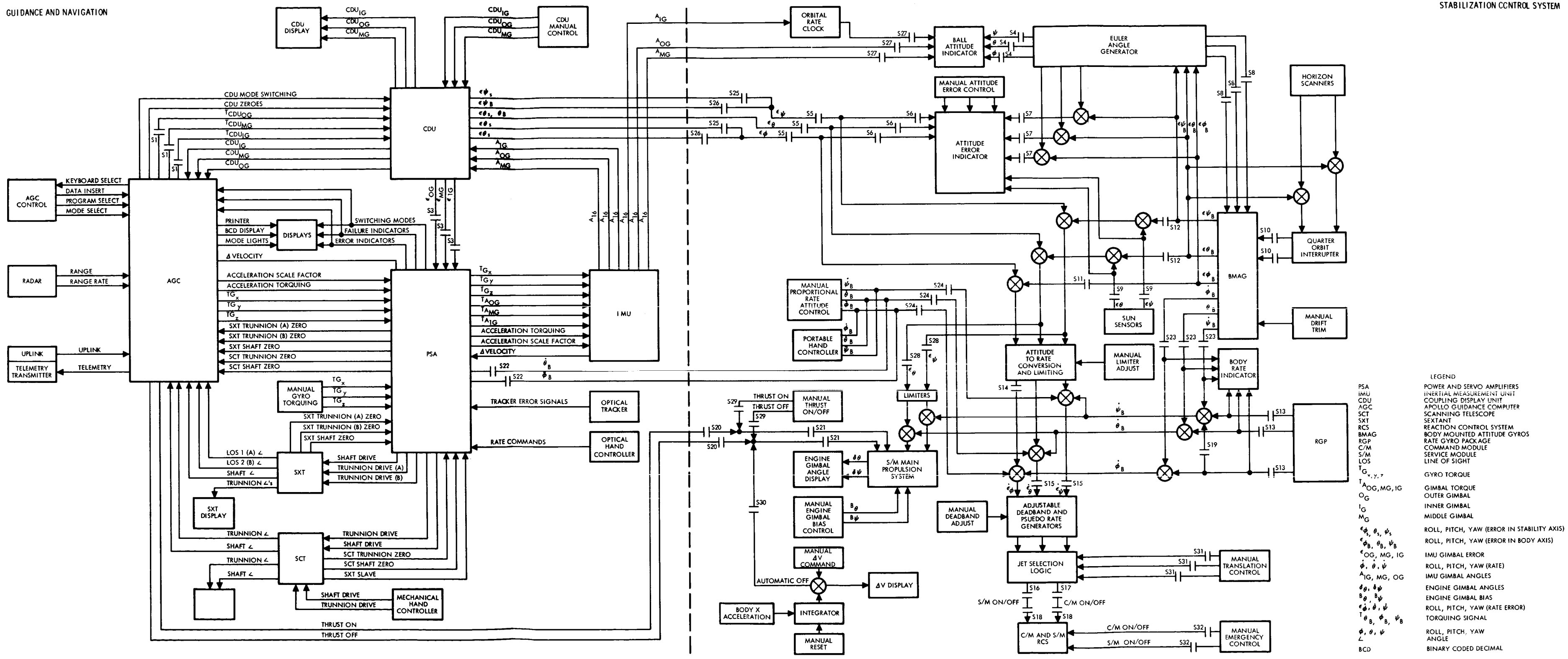


Figure 89. Apollo Guidance and Control Preliminary Functional Block Diagram

# COMMAND MODULE STRUCTURE AND SUBSYSTEM INSTALLATION

## MOCK-UPS

Engineering information was released for the construction of mock-ups 8 (air lock and docking, 10 (life systems), 12 (crew support systems), and 18 and 19 (complete Apollo spacecraft).

Mock-up 3 of the cabin interior (Figure 90) and 5 of the cabin exterior (Figure 91) were completed and was configuration control reviewed by NASA. These mock-ups are being revised to reflect spacecraft design changes.

## BOILERPLATES

The basic structural design effort for command module boilerplates 1, 2, 3, and 19 was completed. A complete set of drawings was released.

The design of the glass-laminate heat shield for boilerplates 1, 2, 3, and 19 was completed. This heat shield was designed to replace the original aluminum alloy aft heat shield, which proved too difficult to fabricate. The glass-laminate heat shield can be fabricated in less time and at lower cost.

Preliminary installation of the aftheat shield, installation of ballast weights, and manufacturing were completed for command module boilerplate 1. The basic structures for command module boilerplates 2, 3, and 19 are in various stages of manufacture.

The command-module-to-service module separation system was changed from the external hook attachment method to a modified thrust point method carrying shear loads with a cable tension tie having separation capability. This necessitated structural redesign of both the command and service modules.

Several design changes were made in the forward parachute compartment area. These included the relocation of parachute and drogue-chute fittings, and redesign of the LES tower leg-well area. Information is needed concerning external insulation requirements for the forward heat shield.

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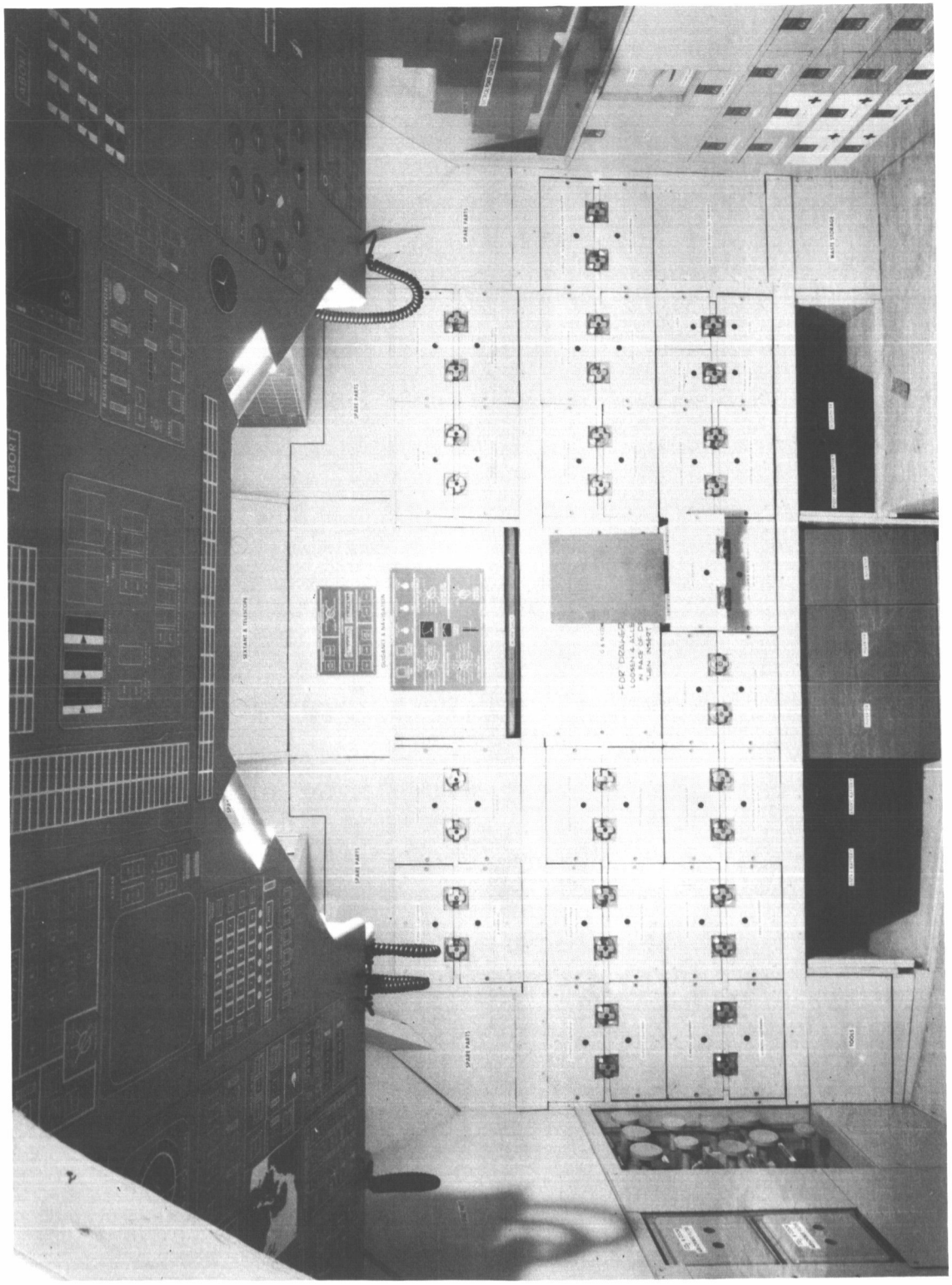


Figure 90. Cabin Interior



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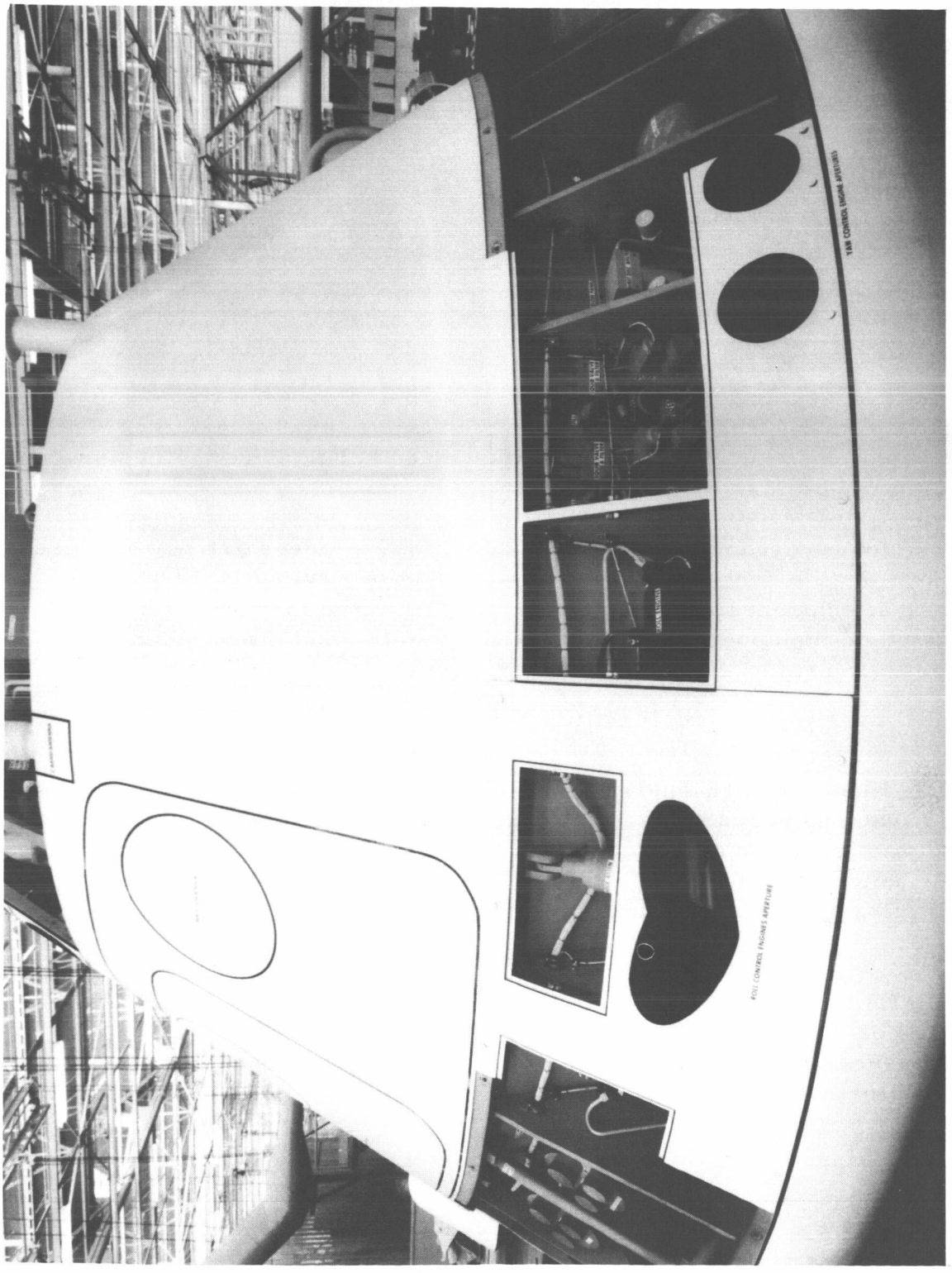


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Figure 91. Cabin Exterior



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Structural subassembly work was started on boilerplate 6, and systems support structure was designed for all known equipment.

The drop test vehicles (boilerplates 1, 2, 3, and 19) are approximately 95 percent analyzed. Various fittings and backup structures have yet to be checked.

A honeycomb structure using fiberglass face sheets and an aluminum-honeycomb core was studied for use as the aft heat shield. As a result of this study, all boilerplate heat shields will incorporate the fiberglass honeycomb structure. The fiberglass heat shield was designed to duplicate the stiffness of the spacecraft.

## BOILERPLATE CREW COUCHES

Crew-couch drawings for boilerplates 20 and 21 were released during the report period. The basic design is the same as that originally released for boilerplates 1 and 2. Pin joints replace 180 bolts where the center-couch carry-through beams adjoin the side-couch beams.

The forward-compartment-cover ejection cylinders are now enclosed in gussets at the forward end of the fixed upper cylinder. The main parachute attachment fittings were removed from the forward bulkhead and located on the upper ring of the fixed cylinder, and the parachute longerons were removed from the inner cabin.

## CREW ACCESS HATCH

The linear-shaped-charge test-program was continued. A series of panels of various gages were sheared with a variety of grains of explosive. The program establishes the approximate required size of the linear-shaped charge to effect separation of the capsule plating and gives some idea of the sound levels which can be expected by the crew.

The evaluation testing of the linear-shaped charges, varying from 5 to 100 grams per foot, was conducted during this report period. Test data were obtained on optimum stand-off, penetration, propagation rate, over-pressure, noise level, fragmentation pattern, and cutting effectivity. Additional tests will be performed during the next quarter to experimentally evaluate the performance of various mechanical-separation and blow-out matches and launch-escape-tower separation.

Figure 92 shows a panel before evaluation of a lunar-shaped charge. Figure 93 shows a panel after this test.

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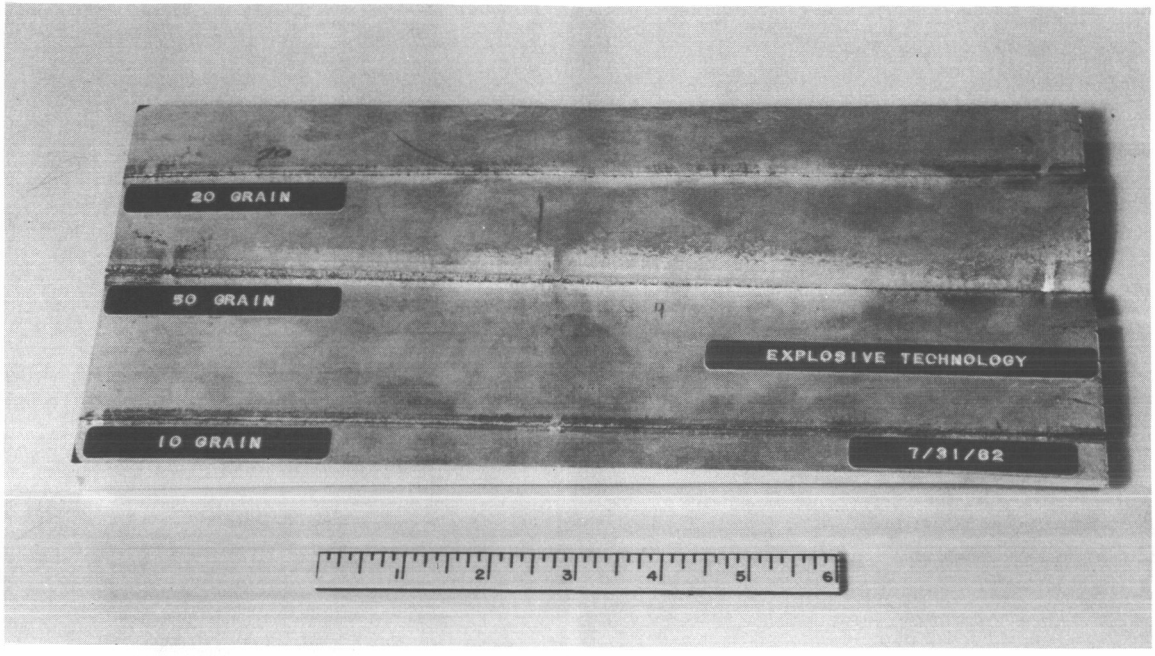


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Figure 92. Panel Before Evaluation of a Linear-Shaped Charge

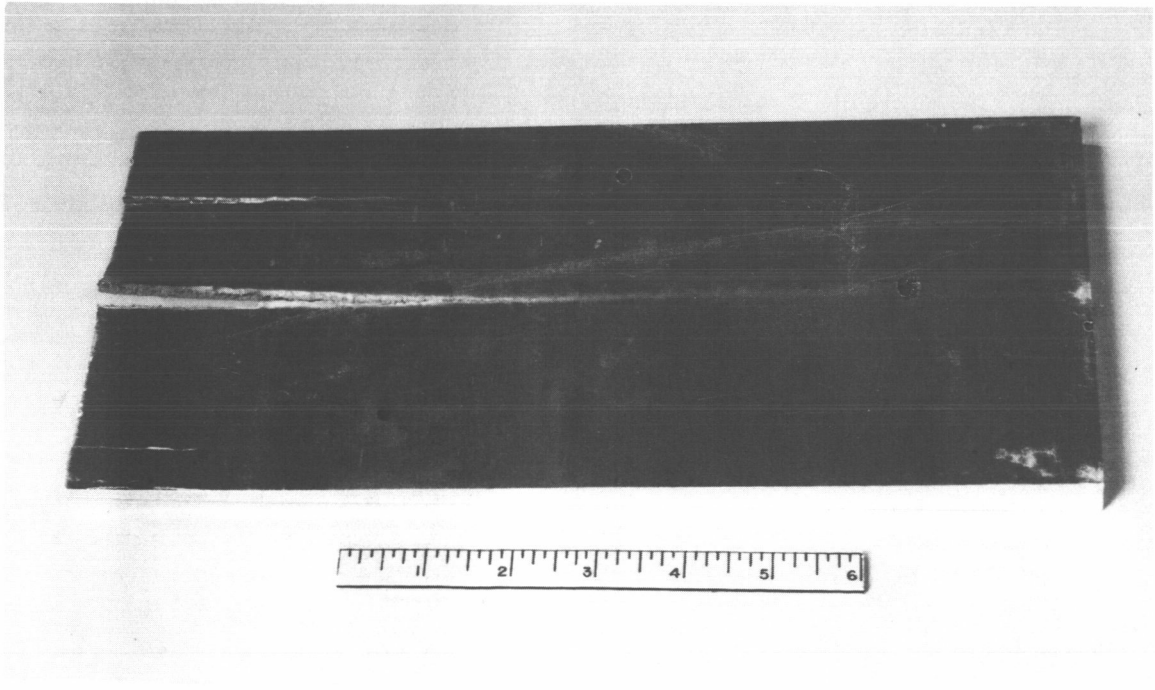

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Figure 93. Panel After Evaluation of a Linear-Shaped Charge



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Design work was accomplished on a more-sophisticated simulation of the spacecraft joint around the access door jamb, together with the necessary back-up structure to protect the crew from the effects of fragmentation.

Gas-generator simulators and restrainers were fabricated and tested to develop experimentally the forward heat shield separation and ejection system. These tests will continue through the next quarter, resulting in a full-scale heat shield separation test.

## HEAT SHIELD

During this quarter, basic design layouts of the command module outer structure (heat shield substructure) have been continued to 95 percent of completion. Preparation, release, and maintenance of detail hardware drawings reflecting the configuration adopted during this period are continuing. Sixty-five percent of all planned spacecraft outer-structure drawings were released.

All spring-loaded doors were eliminated, as well as the external command-to-service-module umbilical and tension connections.

## IMPACT ATTENUATION SYSTEMS

Studies were completed concerning the removal of the vehicle impact-attenuation system. Effort thus far indicates that, if weight is to be eliminated, the criteria must be revised to allow either water landings only, or primary water landings with emergency ground landing to replace the present primary ground landing provision. A two-part proposal has been initiated which outlines the effects upon criteria, structural weight, and hardware requirements. The proposal also contains a schedule for water landings only and a schedule for primary water landings with emergency ground landings.

The aft heat shield shock attenuation system for boilerplates 20, 21, and 23, has been released. This system uses six X-X axis air-oil shock struts and eight horizontal crushable honeycomb struts. Since initial release, redirection of the boilerplate program has resulted in the deletion of boilerplates 5, 20, and 21, and the move of attenuation requirements for boilerplate 20 to boilerplate 6.

Drop-testing of the air-oil X-X struts has started. Load-stroke curves and g levels closely follow theory. Small anticipated modifications to the metering pins will be required.

## AIR LOCK AND DOCKING

The air lock was removed and the fixed cylinder was designed for docking loads.

Several interchanges of design criteria have led to the deletion of the air lock in favor of a single hatch located along the forward entry trunk in the parachute compartment. Docking will be made with a closed hatch, and from the cabin environment. The single hatch will be opened and personnel transfer made only after latch-up sealing, and equalization of pressure with the lunar excursion module.

Except for personnel transfer, the single hatch will be used only for command module emergency egress. At such time, cabin pressure will be vented to space.

## INNER STRUCTURE

Sixty-four percent of the production drawings were released. Design changes included reduction of the forward bulkhead thickness to 3/4 inch, addition of our supporting gussets between the bulkhead and air lock fixed cylinder, incorporation of five observation windows, combining the Xc 42.665 frame with the internal equipment shelf, and revision of the aft side-wall to incorporate the direct command-to-service-module tension tie.

The inner cabin pressure was reduced from 7 psi to 5 psi, resulting in a weight-saving of 20 pounds. The burst-pressure factor was reduced from 2.0 to 1.5 causing a weight reduction of 15 pounds. The main areas reduced were the aft bulkhead, the blowout panel, and the hatch.

The center ring (Xc 42.665) incorporated the use of the equipment bay shelves as structural members. This change lightened the command module by 150 pounds.

## SPACECRAFT CREW COUCHES

In the process of detail design, the MIT navigation and guidance sextant-mounting face has extended considerably beyond the interface into the volume used by the crew-couch foot support during impact attenuation. To provide this additional space, the center couch angles at impact were changed from those of the outboard couches. The angle of the center couch back-support-to-seat-pan is now 100 degrees (102 degrees on the outboard couches). The angle of the seat-pan to lower-leg support is 98 degrees (102 degrees on the outboard couches). The back-support angle to the horizontal plane remains at 12 degrees for all couches. An open-toe foot restraint will also be used to provide the required clearance.

A moveable upper-arm support (in addition to the adjustable forearm support) is now being designed for each couch. The upper-arm support is at a small angle to the back, for normal couch-support angles, and becomes parallel to the back plane when the couch is adjusted out flat. The forearm support is adjustable from an angle of 90 degrees to the back plane to a position parallel to the seat pan.

A number of design studies were completed on couch-adjustment concepts, actuating mechanisms, and control linkages. To place the various operating controls in convenient positions so that they can be readily operated by a man on the couch is more complicated than originally estimated. Installation of the couches with a minimum side clearance adds to these design problems.

Removal, stowage, and reinstallation of the center couch is a major design problem. The present approach to stowage of this couch is to first remove the basic support assembly (back structure, seat pan, and the remaining body-support components) from the two cross-support beams. This is accomplished by the pulling of four pins. The center-couch beam segments are then to be removed from the couch unit and stowed separately. An alternate method is to clip the beams to the outboard side of the center couch before placing the total assembly under the left-hand couch.

## PARACHUTE COMPARTMENT AND FORWARD BULKHEAD

The forward bulkhead was changed from a two-inch honeycomb plate to one 3/4 inch thick. This was made possible by the addition of four gussets positioned radially above the inner-cabin longerons. The longerons were redesigned and now function with the gussets to provide a single beam supporting both the forward bulkhead and the fixed upper cylinder.

## SYSTEMS SUPPORT

The interface between the primary structure and the navigation and guidance system platform is currently being studied and negotiated with MIT. Special problem areas, including the stabilization and control system (SCS) horizon scanner and sun-sensor installations, are also under study.

The relocation of equipment, particularly in the lower equipment bay, has been studied. Arrangements were obtained which will aid in the solution of center of gravity location problems.

## WEIGHT CONTROL

An extensive trade-off study was made to minimize weight. The results of this study were summarized into categories dependent on the method of accomplishment. Changes that met with approval and required no further study were incorporated in the Weight and Balance Status Report. They represent a savings of almost 500 pounds. The other changes will be presented for consideration separately.

## THERMOPHYSICAL PROPERTIES

The design and development of a high-temperature volume expansion measuring apparatus was completed. Tests were run on polymethyl methacrylate, plexiglas, and Teflon. Specific volume determinations on plexiglass samples deviated about 0.25 percent. The apparatus will be used to test candidate materials for the Apollo ablative heat shield.

A modified version of the apparatus used by Satterthwaite and Ure, for measuring the thermal conductivity of small amounts of ceramic materials at low temperatures, is being constructed to measure ablation material samples having dimensions 1/2 inch in diameter by 1 inch long.

## FORGED RINGS

A study is being made to determine the producibility of 2014 aluminum-alloy rolled-ring forgings. Phase-1 of this study has been completed. The rolled-ring forgings did not satisfy the requirements of the material specification because welded tensile strengths varied from 20 to 50 ksi. Hand forgings which had welded tensile strengths of 44 to 52 ksi satisfied the requirements.

## ELASTOMERIC MATERIALS

Ultra-high-vacuum exposure of various elastomers was initiated. Eight elastomers were exposed for at least 14 days in the $10^{-8}$ through $10^{-9}$ Torr range. Weight losses of the various elastomers were neligible. Based on weight loss, Butyl, Viton-B and silicone appear to be the best. Another eight specimens are being exposed for 14 days.

An analysis of the degradation products evolved from various elastomers is in progress. This study will provide an insight into the mechanisms of ultra-high vacuum degradation, and lead to the compounding of elastomers specifically for ultra-high-vacuum applications.

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## SPACE BEARING TESTS

Investigations into technical literature were begun. Information was sought in the areas of space-bearing design, operational environments, and environmental-testing techniques. Information was obtained on testing techniques in a moderate vacuum up to $1 \times 10^{-7}$ Torr. This may be partially adaptable for the $1 \times 10^{-9}$ Torr vacuum objective of this program.

The design of test fixtures for the test of spherical bearings under multiple space environment conditions is about 30 percent complete.

The latching mechanism from the Apollo escape tower has been selected as a representative device for space-bearing testing. Eight prototype mechanisms will be fabricated for test purposes from the actual design concept.

## APOLLO FLOTATION AND WATER-STABILITY TESTS

During this period, flotation and stability tests were conducted on boilerplate 25 in the temporary water pool at S&ID. Drops were made under varied attitudes and drop heights. The maximum sink speed investigated was 24 feet per second (9-foot drop) at a 15-degree pitch angle.

## BOILERPLATE IMPACT ATTENUATION TESTS

These tests will be conducted both on land and in a temporary pool. Drops will be made up to the maximum vertical-impact velocity of 30 feet per second.

Strain-gaging and calibration of the shock-attenuation-system components has begun.

The interim drop tests will be conducted using 25 channels of recorded data for the first drops and increasing to approximately 80 channels as recording devices and equipment become available. Data recorded during the interim drops will be as follows:

| | |
|---|---|
| Heat Shield | One biaxial acceleration point |
| Command Module Structure | Three biaxial acceleration points |
| Crew Couch (Dummy) | Two biaxial acceleration points<br>One uniaxial acceleration point |
| Heat-Shield Shock-Attenuation System | Load and stroke on 3 of 6 vertical struts |

| | |
|---|---|
| Crew-Support-System Shock-Attenuation System | Load and stroke on 3 of 6 shock struts (x-x and z-z axis) |

A motion picture camera will be mounted on the crew-couch structure to record couch motions. It will focus (with mirrors) on targets at the sides and on the top bulkhead. External cameras will be used to photograph impact velocities, attitude, and stability characteristics.

GSE items will include the positioning trailer, fitted with a support base, a command module sling assembly, a heat-shield sling assembly, and a command-module support stand. The support stand is currently being located and installed.

## PANEL VIBRATION TEST (EFFECTS OF MASS LOADING)

Testing of the honeycomb panels was started and Preliminary experimental data were obtained and the panel configuration was modified accordingly.

The acoustic chamber and test equipment will be utilized in the experimental evaluation of various panel configuration under sonic excitation.

## STRENGTH, VIBRATION, AND FUNCTIONAL TEST OF THE COMMAND MODULE SEPARATION SYSTEM FOR BOILERPLATES 3, 5, AND 9

This test will be conducted and completed before the end of the year before the first flight of biolerplate 1. Operational tests and vibration tests will prove the structural integrity of the release mechanism under normal a and critical flight loads.

## FORWARD COMPARTMENT HEAT SHIELD RELEASE SYSTEM

Four phases of testing will be employed in the development of the release system. Phase-I, the gas-generator test-chamber tests to determine the amount and type of propellant required, has begun. Design sketches have been released, and formation of the fixtures has been started for the Phase-II tests which will verify the operation of the thrusters under environmental conditions. Phase-III and IV test methods are in work.

## THERMOSTRUCTURAL TESTS - BRAZED HONEYCOMB SANDWICH

Two test panels, 1/2 inch x 16 inches x 36 inches brazed L-605 honeycomb sandwich panels, covered with Avco X-5026 ablative, are available and will be tested during the next report period. One panel will be subjected to thermal and load environment, the other to cold-shock conditions.

Load paths from service to command module dictate a need for two additional latch points. These will consist of extendible tension links, heat-closed by latches similar to those on the X-X shock strut. Redistribution of the four strut latches among the six struts, plus the addition of two tension-link latches, will result in approximately equal spacing around the perimeter.

Aft Heat Shield

Following NASA direction, studies were conducted to determine the feasibility of eliminating the deployable aft heat shield. This would restrict crew shock attenuation solely to the couch shock struts, and to such shock absorption as could be derived from structural deformation. The stipulation by NASA that roll orientation no longer be used made the Y-Y axis the critical mode, because there is already insufficient space (spanwise across the couches) to provide sufficient strut stroke in a side-to-side direction requiring lowest g forces on the human body.

Data obtained from drop tests of the 0.25 scale model confirm the need for full-scale stability and g level data before a decision regarding heat-shield attenuation can be made.

Impact Attenuation Component Tests

Testing was started on both the shock struts for the command module shock-attenuation system. The air-oil vertical strut was tested up to impact velocities of 30 feet per second in all of the design-metering pin-orifice combinations. This is the maximum design condition for this strut. Further testing, based on data obtained thus far, will be conducted on modified metering-pin configurations.

The crew support system shock strut tests will be started during the next report period. Data obtained from these tests will include strut load versus time, strut stroke versus time, payload deceleration versus time, ans strut load versus strut stroke.

Impact attneuation system component testing for the command module is well under way and has so far proved the design to be functional.

It has been determined that some additional Y-Y axis crew-couch stroke could be obtained by reducing the couch width or moving the capsule inner walls outboard. The adequacy of the addtional amount of shock absorption gained cannot be determined until test data become available and the curtailment of crew comfort and effect on schedule could be considerable.

In addition to the L-605 panels, six 15-7 Mo honeycomb panels will be tested-some with Avco X-5026 ablative and some with X-5019 ablative material. The 15-7 Mo panels will be tested for comparison purposes under the same conditions as the L-605 panels.

During the next report period, tests will be conducted on the escape tower separation system, the crew-couch and shock-attenuation system, the pressure compartment access, the heat shield release mechanism, and on various other components of the command and service modules.

# SERVICE PROPULSION SUBSYSTEM

## PRESSURIZATION SUBSYSTEM

The pressurization system shown in Figure 94 is basically the same as the system presented during the last report period. An effort to control the climb of propellant-tank pressure above regulator lock up was made. This has resulted in a number of studies.

An engine requirement, the increase of the propellent-inlet steady-state supply pressure, coupled with refined-system pressure-drop calculations, resulted in a revised system pressure budget, as shown in Figure 95.

### Tank Configuration and Distribution System

The propellant tanks will contain a volume of 45,000 pounds of useable propellants. Factors accounted for in sizing the tanks included the oxidizer-fuel mixture-ration shift, trapped propellant, tank-manufacturing tolerances, loading tolerances, and ullage space. These are shown in Figure 96. The tanks are sized to contain the required weight of propellant for the temperature range predicted during the mission. The launch-pad servicing temperatures will be controlled as required.

Design layouts of the propellant-distribution plumbing, which establish the optimum routing and interface, are in progress.

### Preliminary-Flight-Rating Test (Engine Test Stand)

All engineering drawings were completed and released, except for details affected by engine installation.

Structural layouts and tank drawings were revised to accommodate the increased-propellant-tank volume.

At present, structural fabrication is 65 percent complete. One base assembly, all vertical-support assemblies, propellant-tank clamps, and upper platforms are complete.

### Mock-Ups

All propellant system mock-up information drawings have been released for the installation of a simulated-service-propulsion system in mock-up 18. Mock-up 7 is being refitted to reflect the current design concept as defined by these drawings.

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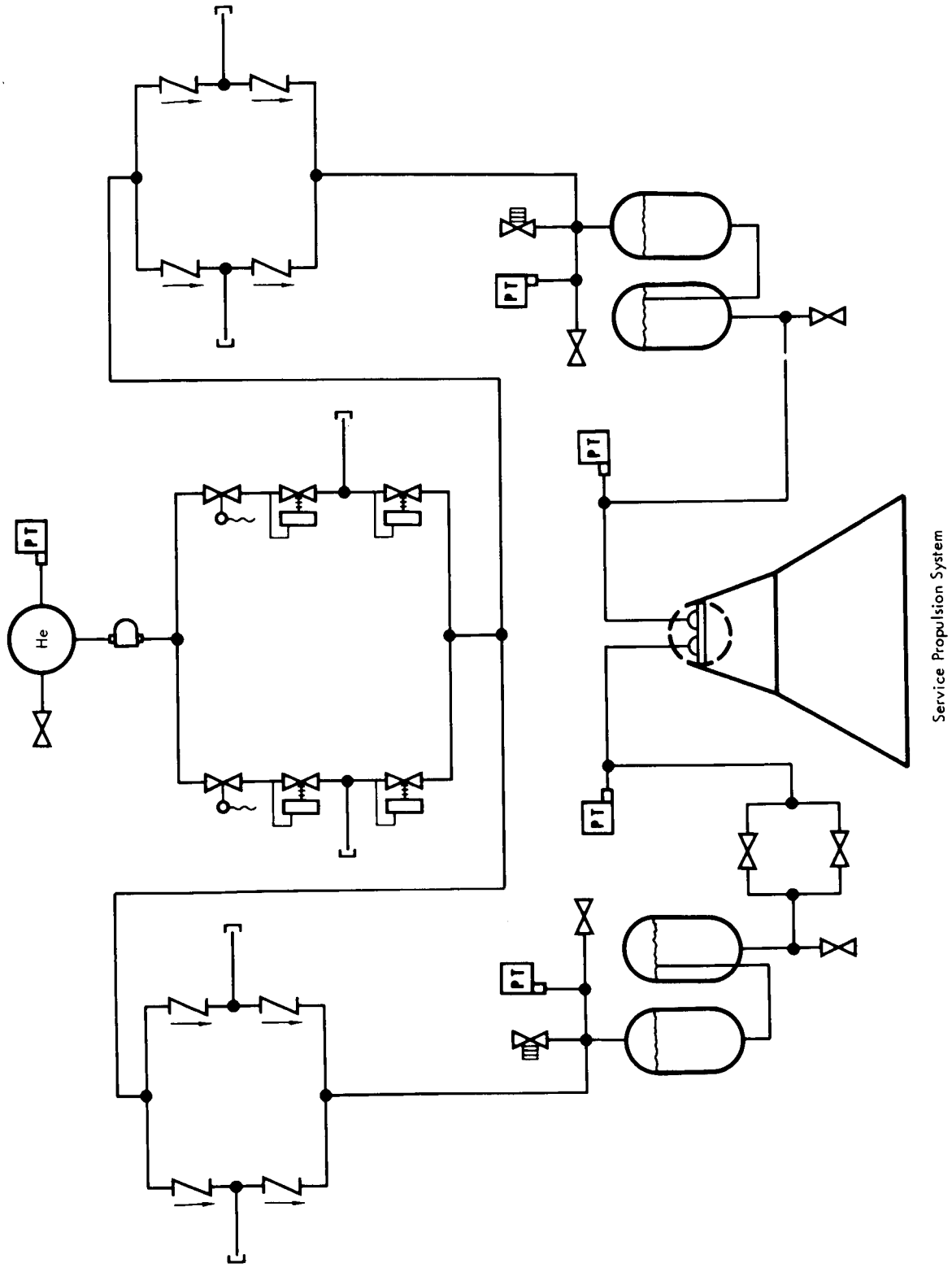
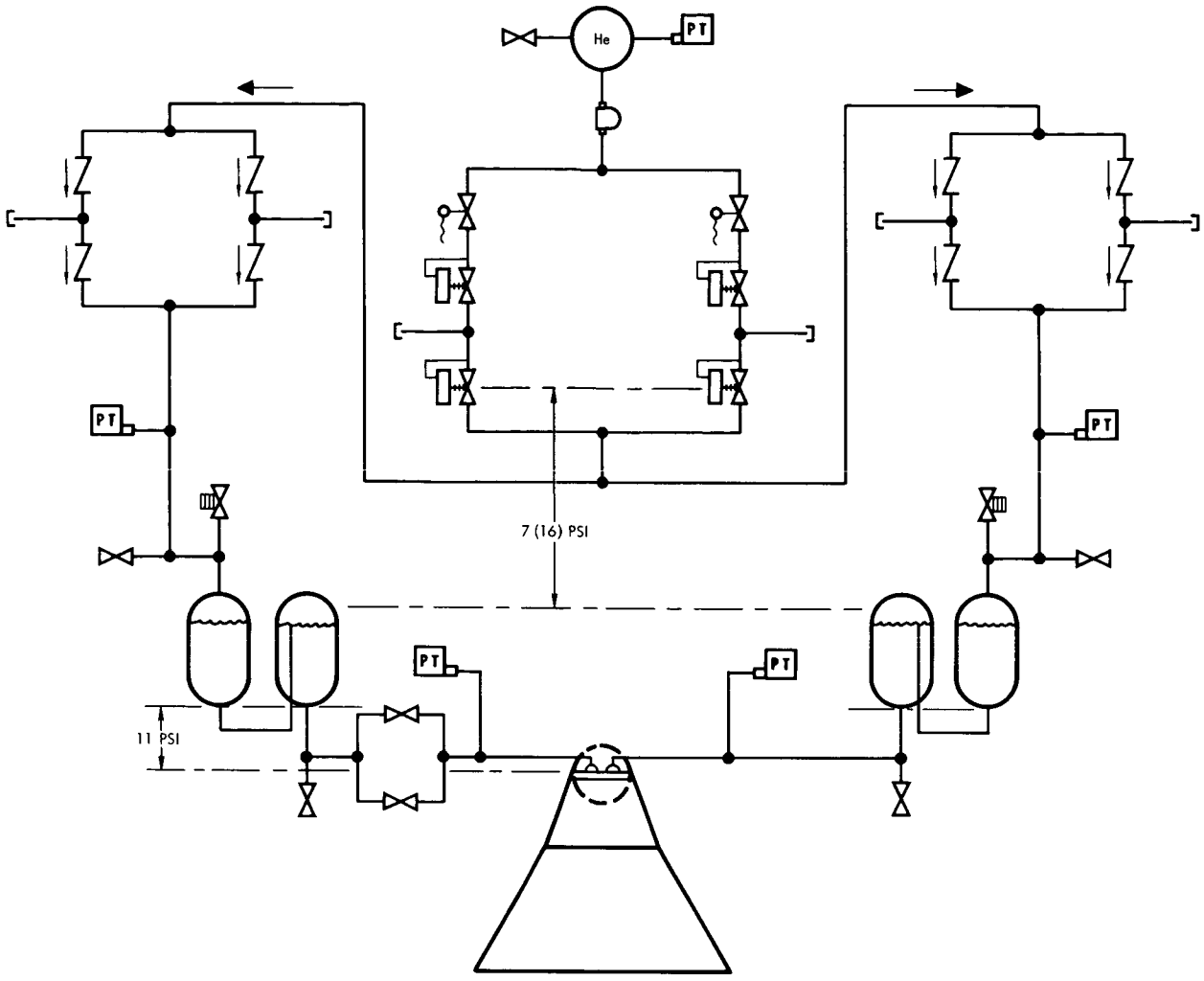



Figure 94. Service Propulsion Pressurization System




SERVICING PROPULSION SYSTEM - OPERATING PRESSURES

| | |
|---|---|
| FIRST STAGE REGULATOR OUTLET | 198(207)$^{\pm 4}$ |
| SECOND STAGE REGULATOR OUTLET | 173(182)$^{\pm 4}$ |
| TANK PRESSURES | |
| · NORMAL OPERATION | 166 $^{\pm 4}$ |
| · SECOND STAGE REGULATOR FAILED OPEN | 171 $^{\pm 4}$ |
| · HELIUM SOURCE ISOLATION FAILED OPEN | 182 (191)MAX |
| TANK RELIEF VALVE AND BURST DISC | 212 MIN<br>240MAX |
| ENGINE INTERFACE | |
| NORMAL START | 166 $^{\pm 4}$ |
| NORMAL RUN | 155 $^{\pm 4}$ |
| SINGLE MALFUNCTION START | 182(191) MAX |
| SINGLE MALFUNCTION RUN | 160 $^{\pm 4}$ |

REGULATOR LOCK UP = MAX RUN +5 PSI

( ) WITH LINE-MOUNTED HEAT EXCHANGER

Figure 95. System-Pressure Budget

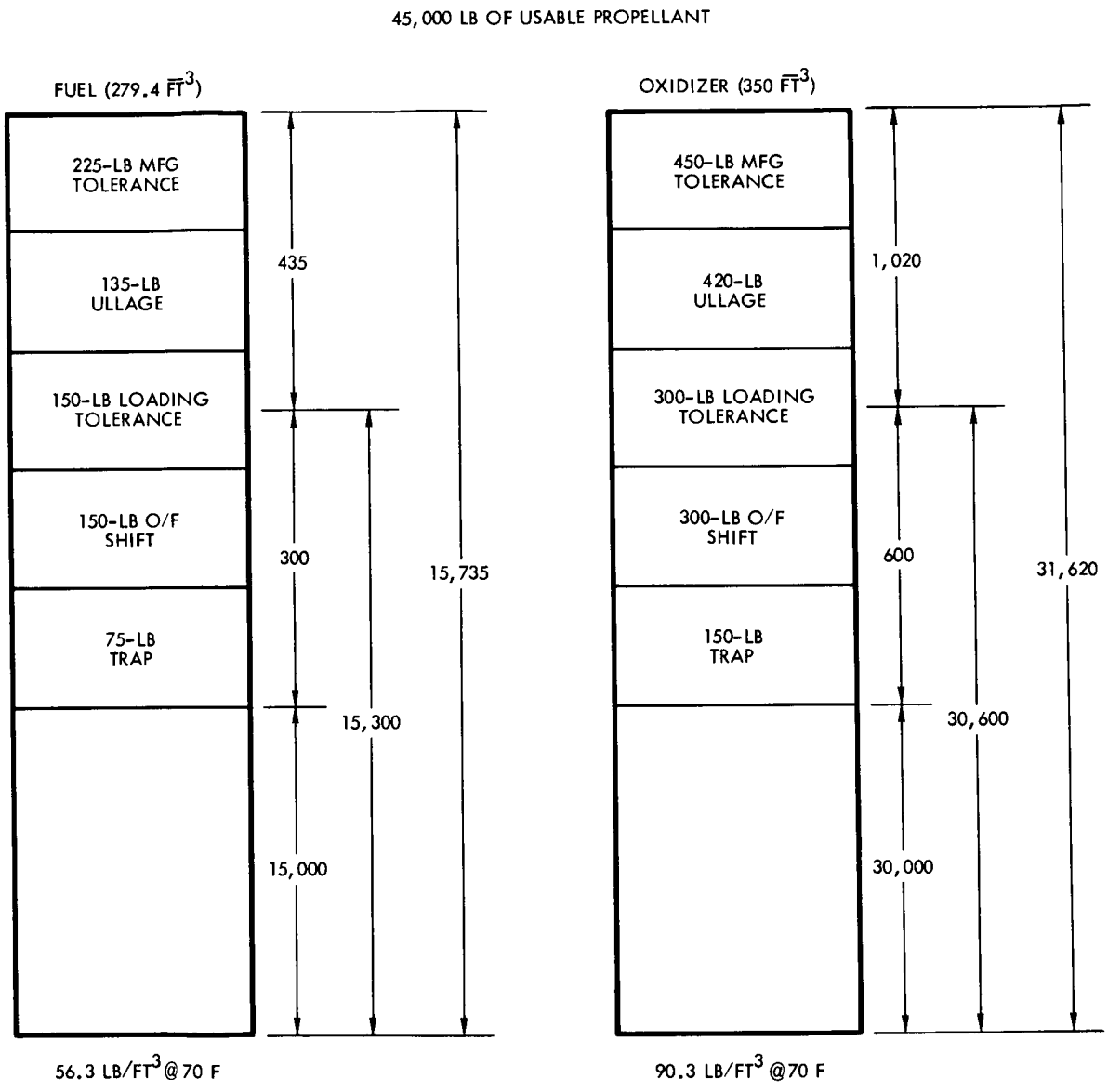



Figure 96. Tank Sizing

## MATERIALS AND PROCESSES

### Seal Evaluation

Fourteen seal-test fixtures were designed and fabricated for use with the helium-mass-spectrograph leak detector.

Rubber "O" rings and TVM seals are being evaluated under conditions of maximum and minimum compression to determine whether the rather wide seal-and-cavity-depth tolerance recommended by the manufacturers can be used.

A sealing-boss design incorporating a dual seal has been developed and pressure-tested with helium to 4500 psig. Two seals are currently being evaluated for use with the boss; both seals are metallic and have a V-shaped cross section, with a dual seal provided by nesting a rubber or Teflon "O" ring inside the V. The rubber "O" ring also provides retention of the metallic seal over the end of the joining tube.

### Tube Brazing and Welding

A brazed sleeve design has been evolved for test purposes. The sleeve is straight through with two alloy grooves.

### Nitrogen Tetroxide

Compatibility tests were completed with several brazing alloys in nitrogen tetroxide. All materials tested showed excessive weight loss, except for the gold-base alloys, which will now be used exclusively in the preparation of brazed tube specimens.

A weight analysis of current propellant-system drawings indicated that the use of AM-350 CRES tubing for the high-pressure helium system could be eliminated without significant weight increase because the lines were so short. The entire propellant system is now based on the use of 304L CRES tubing. CRES 304L was selected over 324 and 347 CRES because it is a cleaner material having fewer inclusions. It also has better brazing-alloy wetting characteristics.

CRES tubing has been welded by the "burn-down butt-weld" technique. This is done by flaring the ends of the tubes to be joined, butting the flared ends, and burning-down the standing flange with a TIG torch. A tool which can be clamped onto the line and which will semi-automatically accomplish the weld, has been designed and is presently being fabricated. Test evaluation of tube specimens will be started during the next report period.

The joining of dissimilar metals has been investigated because many of the components in the basic CRES system will be aluminum or titanium.

Plumbing

A split-induction coil is being fabricated for tube brazing. This tool will permit the use of a protective atmosphere or vacuum for in-place brazing applications.

A new stainless steel union has been designed and produced. The new union has less over-all mass and is easier to heat. Several specimens were successfully brazed. They are now being helium-leak-checked at $2 \times 10^{-6}$ cc of helium-per-second, prior to tensile testing.

Ten specimens of aluminum-to-steel tubing were brazed to establish the feasibility of joining these materials with aluminum-brazing alloys. The brazed specimens were leak-checked between heat treatments. Results indicate that this process is feasible.

Compatibility tests and melting-point determinations were made for various solders. Testing to evaluate sealing characteristics and to determine joint configuration and allowable tolerances will begin shortly.

Expulsion Devices

During this report period, activities were directed toward the design and fabrication of positive expulsion devices. Both elastomeric bladders and stainless steel bellows were investigated. Fabrication feasibility investigations will continue, and expulsion test devices will be fabricated and tested.

Propellant System Seal Tests

Testing of the propellant system seals was started during this report period. The test hardware for nine configurations was fabricated. It is now being fabricated for five more configurations. Successful hydrostatic tests and helium-leakage tests were completed.

## SERVICE-PROPULSION ENGINE

Design Changes

Three design changes were made in the service-module propulsion engine during the past report period. The expansion ratio of the radiation-

cooled nozzle extension was increased from 40.1 to 60.1. The engine compartment diameter was reduced from 50 inches to 44 inches. The gimbal location was moved to the engine throat.

## Expansion Ratio Discussion

The expansion ratio was increased from 40.1 to 60.1 as the result of a parametric study in which a trade-off between weight and specific impulse was investigated. This study considered a change in propellant weight, engine weight, tank weight, service-module-structure weight, and adapter height and weight. The minimum specific impulse (-3 at the end of 750 seconds of operation) increases from 313 seconds to 318.7 seconds. The expansion ratio increase results in a net weight reduction of 675 pounds.

## Engine Performance

The revised engine performance is as follows:

| | Initial | Final at 750 sec |
|---|---|---|
| Chamber pressure, psia | 100 | 95 |
| Thrust (lb) | 21,935 | 22,865 |
| Oxidizer-to-fuel ratio | 2:1 | 2:1 |
| Specific impulse (sec) | 323.0 | 321.7 |
| Specific impulse (-3 low) | 320.0 | 318.7 |
| Oxidizer flow rate (lb/sec) | 45.273 | 47.384 |
| Fuel flow rate (lb/sec) | 22.636 | 32.692 |

## Throat-Gimbal Location

Shifting the gimbal location from the forward end of the engine to the throat is advantageous from several standpoints. The mass moment-of-inertia is reduced, because motion takes place essentially about the center-of-gravity of the gimbaled mass. This results in a reduction of gimbal-actuator power requirements. The angular-acceleration requirement has been reduced from 5 radians per second squared to 3-1/2 radians per second squared, which also reduces the actuator peak-power-load requirements.

The clearance required to gimbal the engine has also been reduced to permit the engine to be inserted farther into the spacecraft with an engine compartment of smaller diameter.

Engine Installation

Several design layout studies were made to determine a mutually-compatible engine configuration that would function in the 44-inch-diameter engine well. Flexural pivots and lubricated bearings are both being studied for use as gimbal bearings. Since the flexural pivot is larger than conventional bearings, the layouts were made using flexural pivots. Layouts had previously determined that the 42-inch-diameter well in the service module would not be adequate for gimbaling clearances, assuming that the thrust vector over-shoot angles required to control the center of gravity excursions would be 5 degrees.

The engine centerline is now indexed at 4 degrees from the vehicle centerline, with a gimbal angle of ±9 degrees. The intersection of the gimbal axis is located at service-module station 206. 0 (Apollo station 844. 0).

The gimbal actuator geometry, loads, and power requirements have been determined. The propellant feed lines will be hardlines mounted on the engine with flexible joints 90 degrees apart provided at the gimbal axis. The engine-to-service-module interfaces have been located and dimensions established.

Studies are in progress to determine a location for the engine-propellant drains-and-venting overboard exhaust ports that will meet both functional and safety requirements.

Injector Test Program

Four injection patterns were fired using modified stainless-steel Titan injectors. These configurations included a quadlet (2 fuel and 2 oxidizer streams impinging at a common point), a triplet (2 fuel streams impinging on one oxidizer stream-close impingement),a triplet with a long impingement distance, and a long-impingement triplet drilled for low $\Delta P$. Injector test results are indicated in the following table.

| Injector | No. Tests | Remarks |
|---|---|---|
| Quadlet | 3 | Unstable operation |
| Triplet (Short impingement) | 6 | 34 in. and 50 in. L* unstable operation better than quadlet |
| Triplet (Long impingement high $\Delta P$) | 12 | Stable operation. 10 tests with ablative chamber, for a total time of 129 seconds. C* = 5320 |

| Injector | No. Tests | Remarks |
|---|---|---|
| Triplet (Long impingement, low $\Delta P$) | 8 | Unstable operation in stability motor indicates tangential mode instability. |

Ablative Chamber Tests

Ten firings were accomplished on a heavy-wall ablative chamber for a total firing time of 129 seconds. These were made with a long-impingement high $\Delta P$ triplet injector, which indicates a C* of 5320 feet per second. This value represents 97 percent of Apollo specification value of 5490 seconds. The chamber and injector will be further tested in conjunction with an evaluation of nozzle-flange temperature.

Design Reviews

The service propulsion engine procurement specification was revised and updated to include the latest performance data and environmental criteria. This specification will be released during the next report period.

The status of hardware in fabrication is shown below.

| Item | Units Complete | Units in Work | Remarks |
|---|---|---|---|
| Injector modified Titan | 3 | 1 | 1st unit reworked |
| Injector prototype | 0 | 21 | 2 nearing completion<br>1 October 1963 |
| Chamber uncooled steel | 3 | 2 | 34, 40 and 45 in. L* |
| Chamber water-cooled | 2 | 2 | 34, 40 and 45 in. L* |
| Chamber ablative | 6 | 34 | Heavy wall and flight weight |
| Valve | 2 (Prototype bar stock) | 20 | Prototype for bench testing |
| Gimbal actuator | 0 | 14 | Subcontract |
| Gimbal ring | 0 | 0 | Complete first unit<br>1 November 1962 |
| Propellant lines | 0 | 0 | Start fabrication<br>21 September 1962 |
| Nozzle | 0 | 14 | Complete first unit<br>1 December 1962 |

# SERVICE MODULE STRUCTURE AND SUBSYSTEM INSTALLATION

## MOCK-UPS

The service modules for mock-ups 9 and 11 were completed before the design change in length, but were retained for use by the addition of a spacer that compensated for length difference. These two mock-ups are handling and transportation items not affected by internal assembly considerations.

## BOILERPLATES

A requirement to reduce service module weight for use on the C-1 booster configuration resulted in an expedited effort to change the structure for boilerplates 9, 13, 15, 16, and 18 from steel to aluminum. The first steel boilerplate service module has been completed and will be used as boilerplate 12.

## WEIGHT CONTROL

The configuration on which weights are currently being reported is sized for the lunar orbital rendezvous mission with a 25, 000 pound lunar excursion module.

## EQUIPMENT INSTALLATION

During this period, the main-propellant-tank capacity has been changed from 31, 000 to 39, 500 to 45, 000 pounds.

The tank drawings were completed.

## ANTENNA FOLDING MECHANISM

A design study is in progress to define a configuration for the antenna folding mechanism appropriate for the revised service module arrangement.

## RADIATOR

The requirement for the radiator-door deployment system which had been investigated was eliminated by redirection to the lunar orbital rendezvous mission only.

## REACTION CONTROL MOTOR DEPLOYMENT

A system configuration previously defined will no longer be appropriate due to the rearrangement of equipment in the service module associated with redirection to lunar orbital rendezvous mission only.

## SEPARATION SYSTEMS (COMMAND-TO-SERVICE MODULE)

During the last period, the separation system was completely redesigned. The heavy-bend hold-down arms were eliminated, and direct ties through the heat shield were designed.

A study was conducted to investigate elimination of the complexity and potential hazard of the five close-out doors of the previously-considered separation system. A new system was devised that eliminates the close-out doors, preserves the thermal integrity of the command module at all times during the mission, and affords a significant weight saving over the earlier system. The configuration of the new system has been established and approved, and detail design of this system is in progress.

The command module will be attached to the service module by three studs and retention latches. Tension loads are transferred directly along the axis of the studs. The studs are attached to the command module by thermal insulators at locations on the aft spherical face. They protrude through the ablation material and will remain with the command module after separation. The protruding studs, which are insulated from the command module, are quite small and will burn off during reentry. Three latches, mounted on the service-module structure, engage the studs to complete the tension connection. The latches, which are maintained in the engaged position by a preloaded cable, are sequence-triggered to unlatch for separation by retraction of the umbilical-disconnected thruster mounted on the forward bulkhead of the service module.

Umbilical penetration of the aft heat shield has been devised using a structural panel equipped with disconnects on either side.

Compression loads are transferred through three compression pads which have circular flanges that are adjustable by means of eccentric cams. The flanges fit into cylindrical depressions in the command module ablation material. Shear loads are transmitted from the compression pad flanges to the cylindrical depressions.

The former system consisted of latches and umbilicals requiring thermal protection provided by five doors. The new design moves the tension ties and umbilicals inboard and eliminates the doors. Thermal protection is maintained and system weight is reduced.

## SERVICE MODULE AND ADAPTER INTERNAL LOAD

Three IBM programs were coded to determine the internal loads of the service module and adapter. Two of these programs are operational; the third is being corrected.

## STRUCTURAL SHELL CONFIGURATION

Work was started on a study to replace the outer shell of the present configuration with a stressed outer shell. The outer shell of the present configuration does not take any loads due to body bending or axial thrust. By designing the joint between the service module and the adapter to act as a continuous connection, the outer shell would carry body-bending and axial loads and a more-efficient structural configuration would be achieved.

The outer shell and radial beams were resized, and various joints between the service module and adapter interface are being studied.

## WEIGHT CONTROL

The curves shown in Figures 97 were obtained by utilizing IBM 7090 output data and the cathode ray rube plotter, present configuration center-of-gravity, mass-moment-of-inertia, and product-of-inertia variations for the main-propulsion-propellant usage. These data are based on a configuration which includes the command module, service module, and lunar excursion module in the coast position.

## PROPELLANT TANK

The factor-of-safety to be used for the design of pressure vessels was investigated and it was recommended that the factor-of-safety of all pressure vessels be 1.5. The recommendation was accepted and referred to NASA for approval. A considerable weight saving is achieved with these revised criteria.

A stress analysis was made of the major propellant tank specification-control drawings for the main propellant tanks.

## SERVICE MODULE CONFIGURATIONS

A 260-inch-diameter service module was studied at the request of NASA. Four configuration drawings were made, and structural size requirement was established.

Two service module configurations, each having a single tank and common bulkheads, were studied at the request of NASA.

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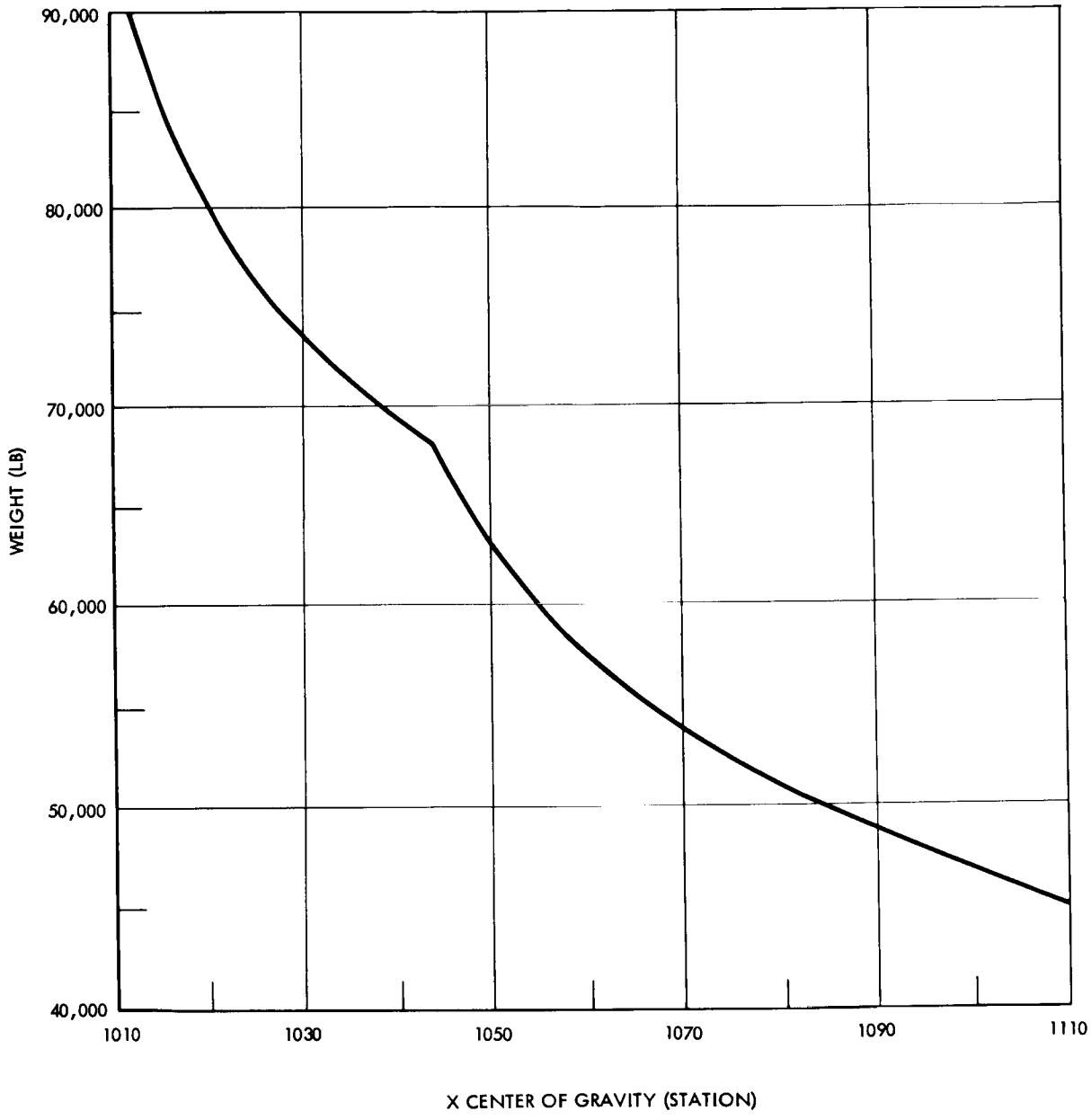


Figure 97. Command Module, Service Module, and Lunar Excursion Module (Sheet 1)

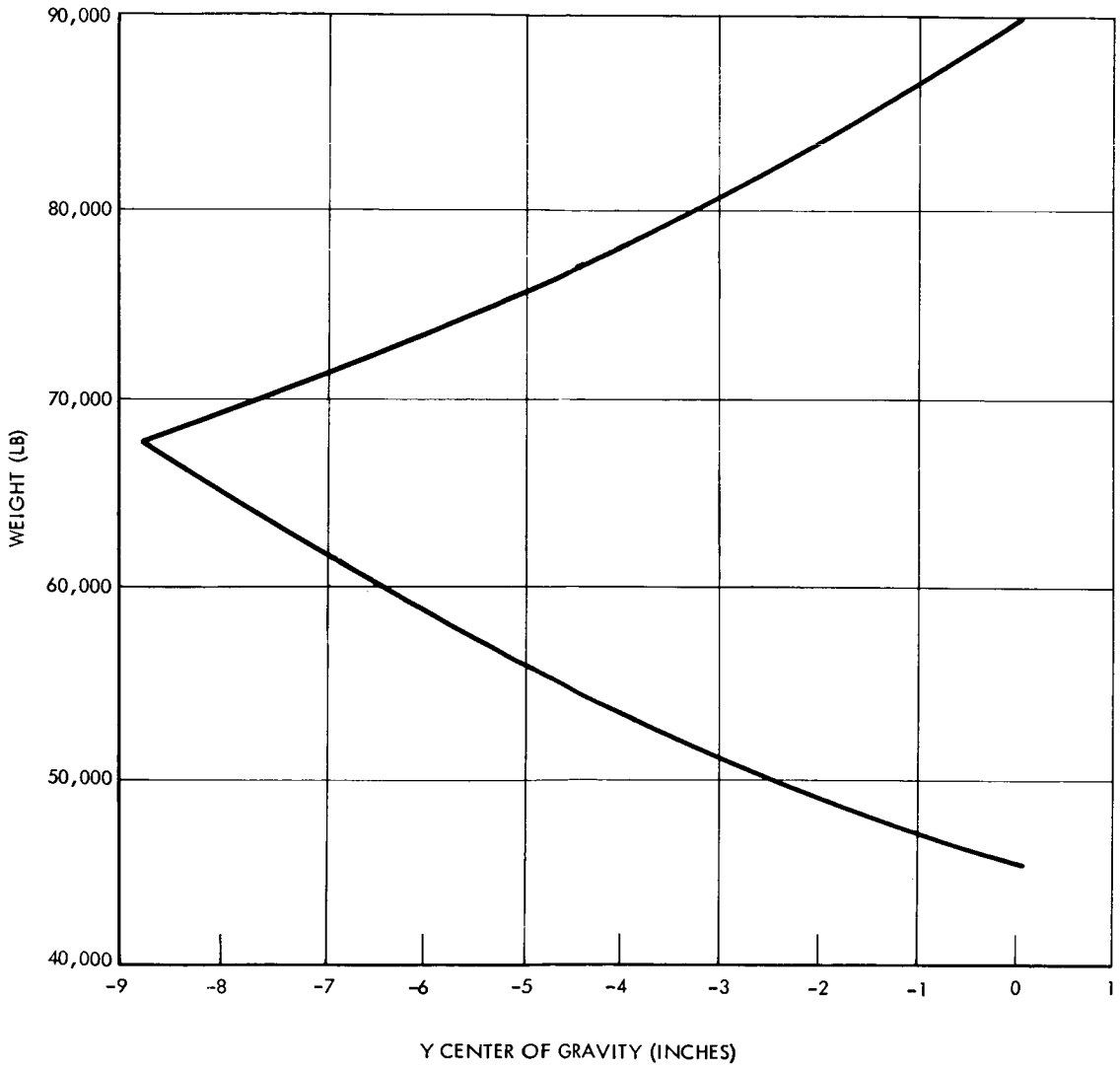


Figure 97. Command Module, Service Module, and Lunar Excursion Module (Sheet 2)

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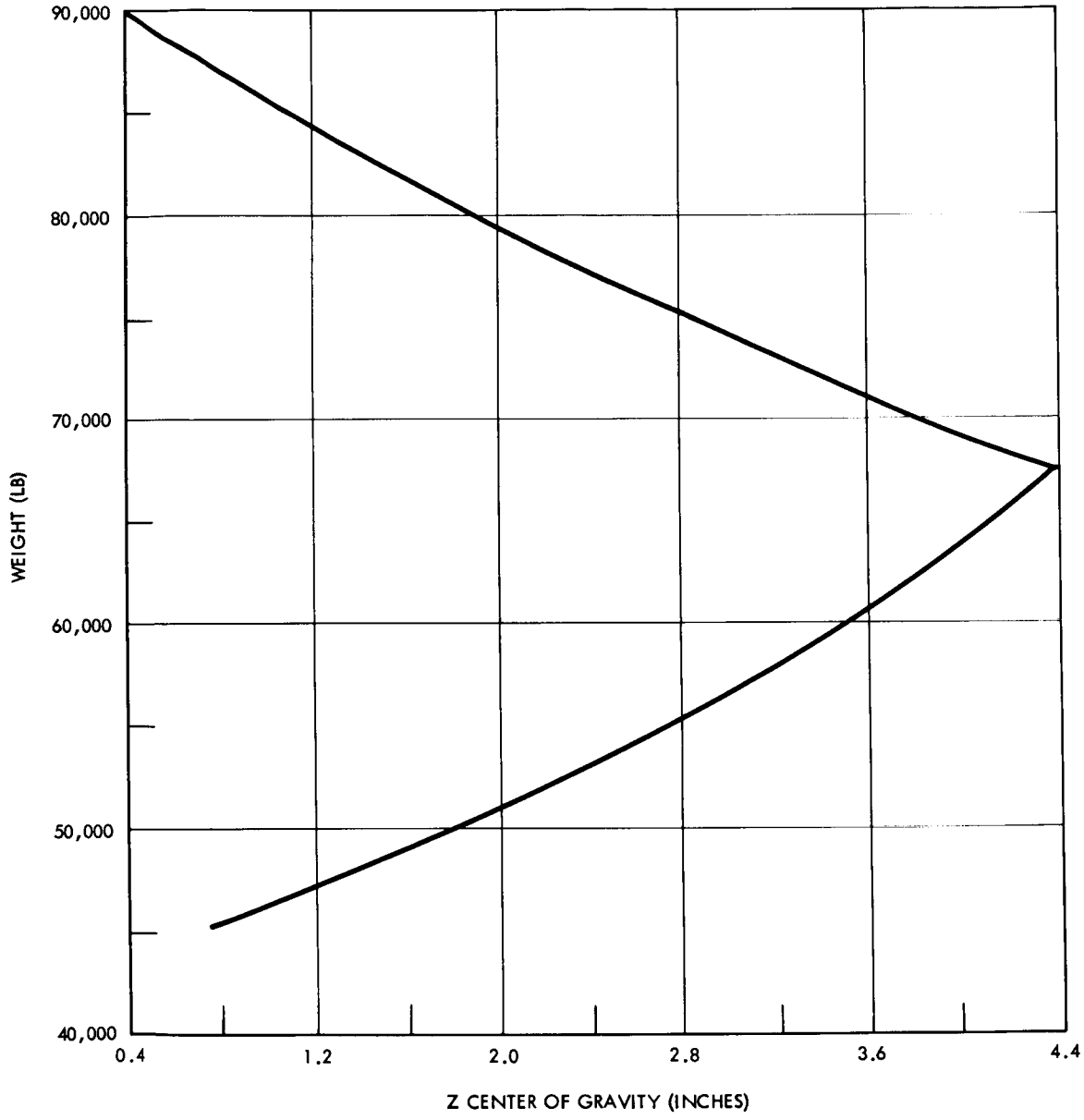


Figure 97. Command Module, Service Module, and Lunar Excursion Module (Sheet 3)

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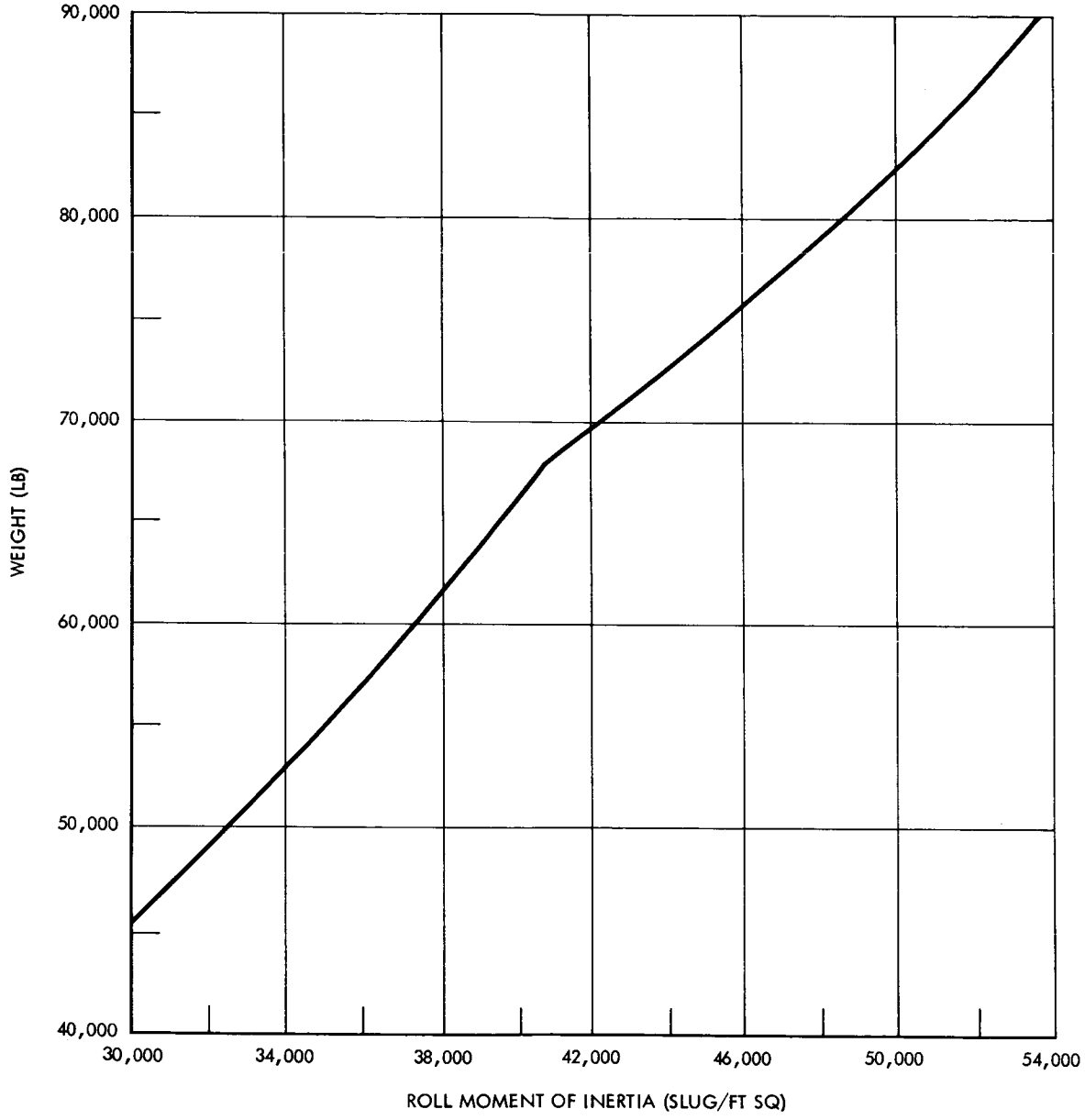


Figure 97. Command Module, Service Module, and Lunar Excursion Module (Sheet 4)

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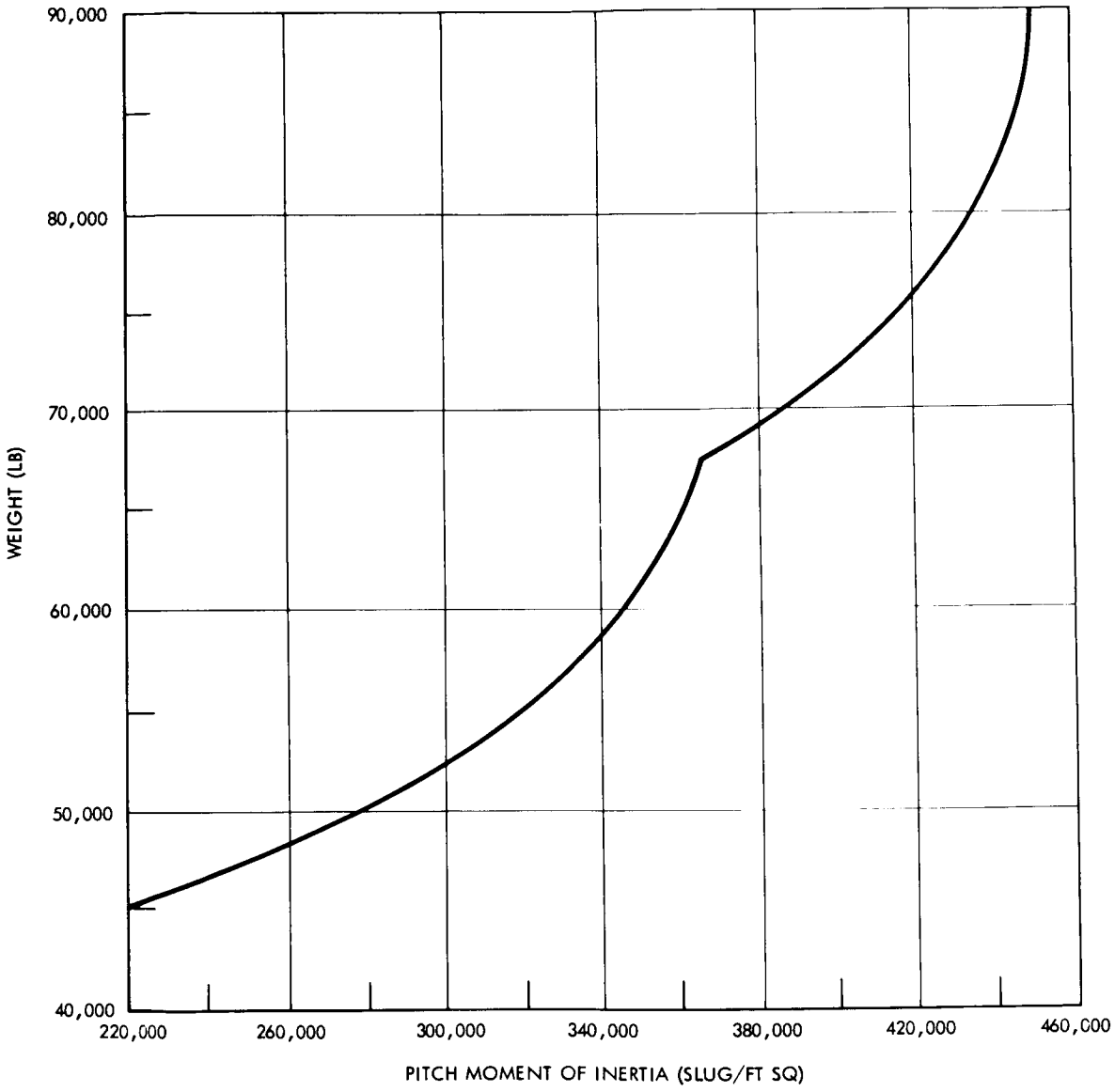


Figure 97. Command Module, Service Module, and Lunar Excursion Module (Sheet 5)

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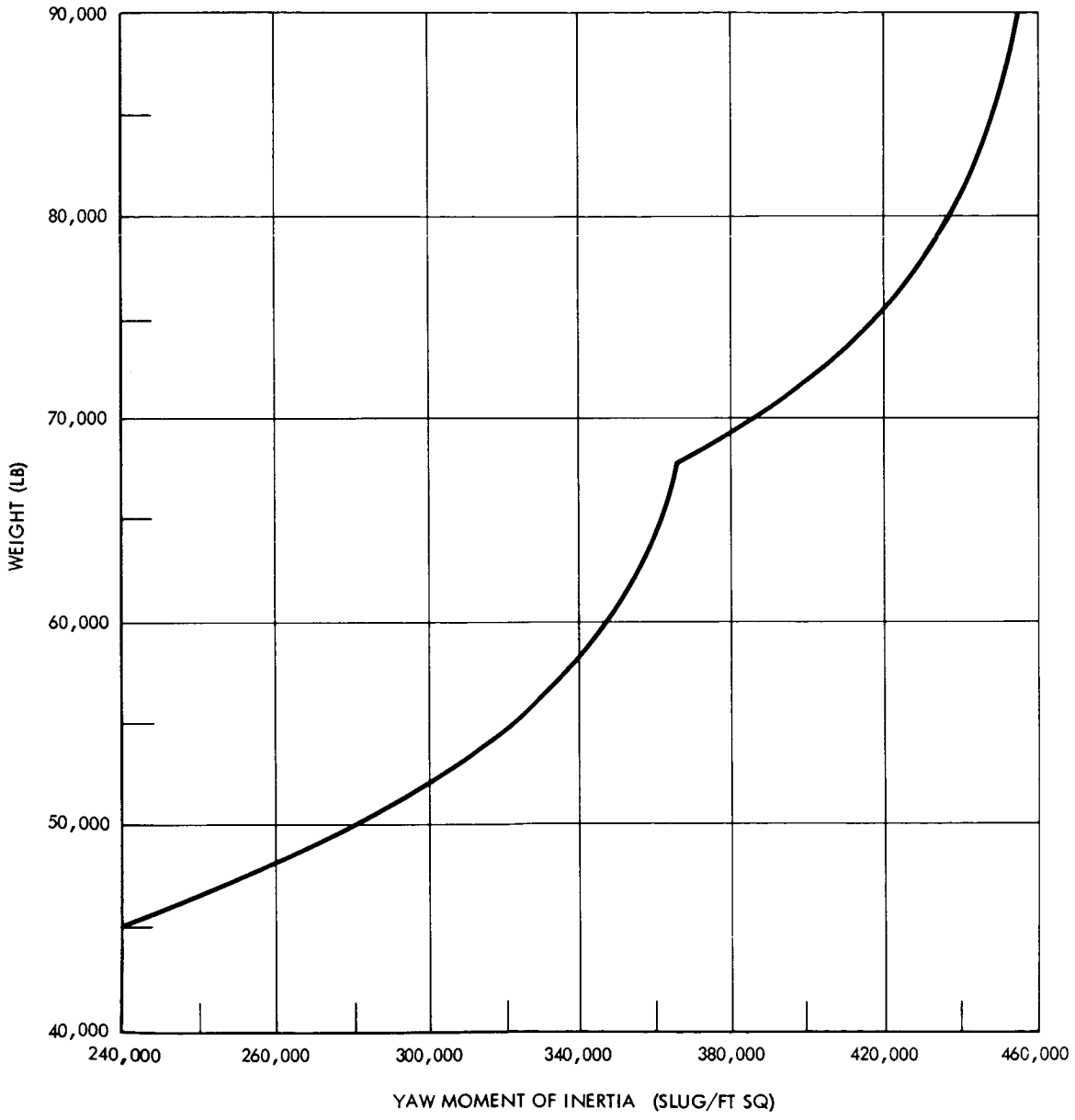


Figure 97. Command Module, Service Module, and Lunar Excursion Module (Sheet 6)

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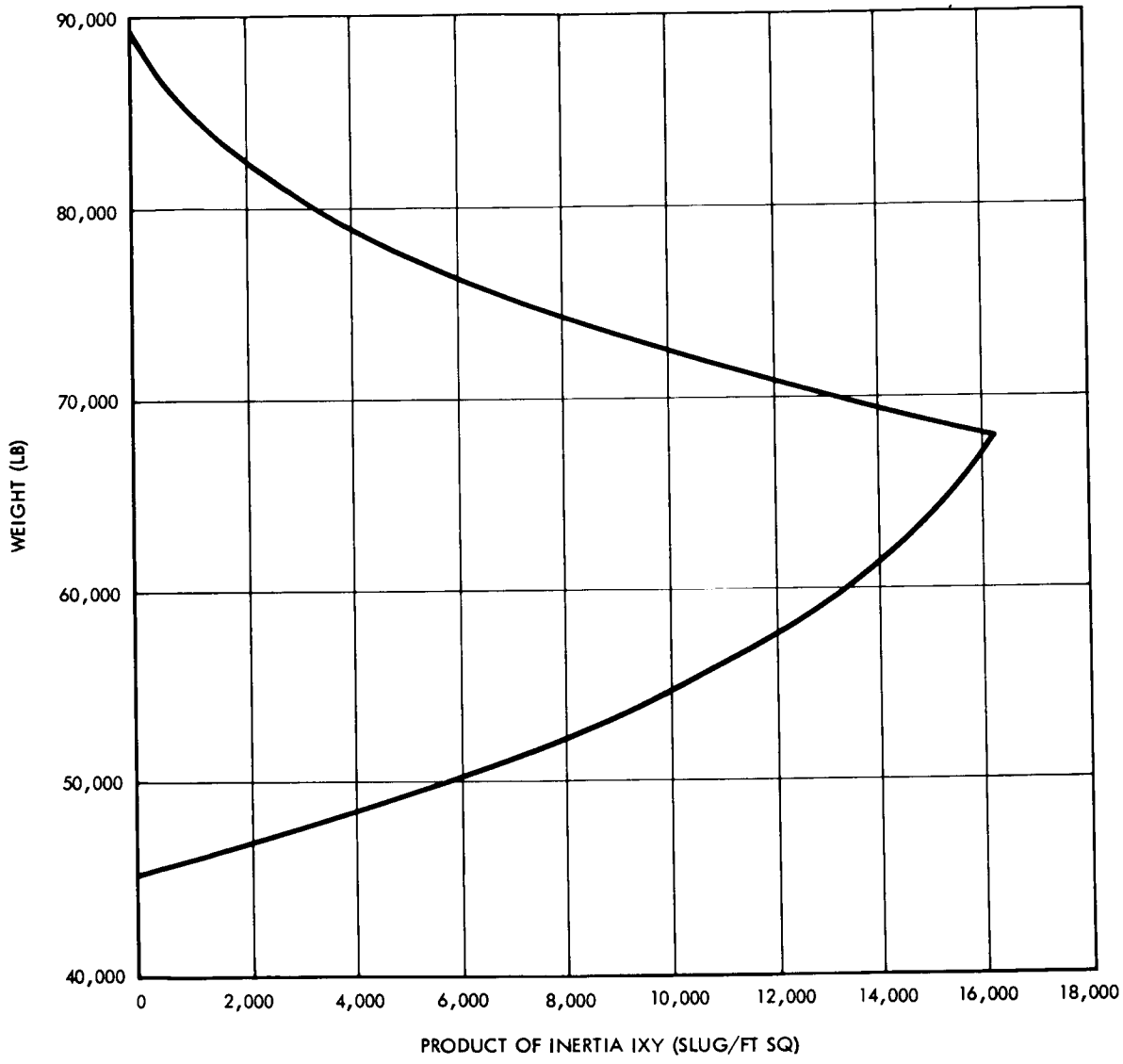


Figure 97. Command Module, Service Module, and Lunar Excursion Module (Sheet 7)



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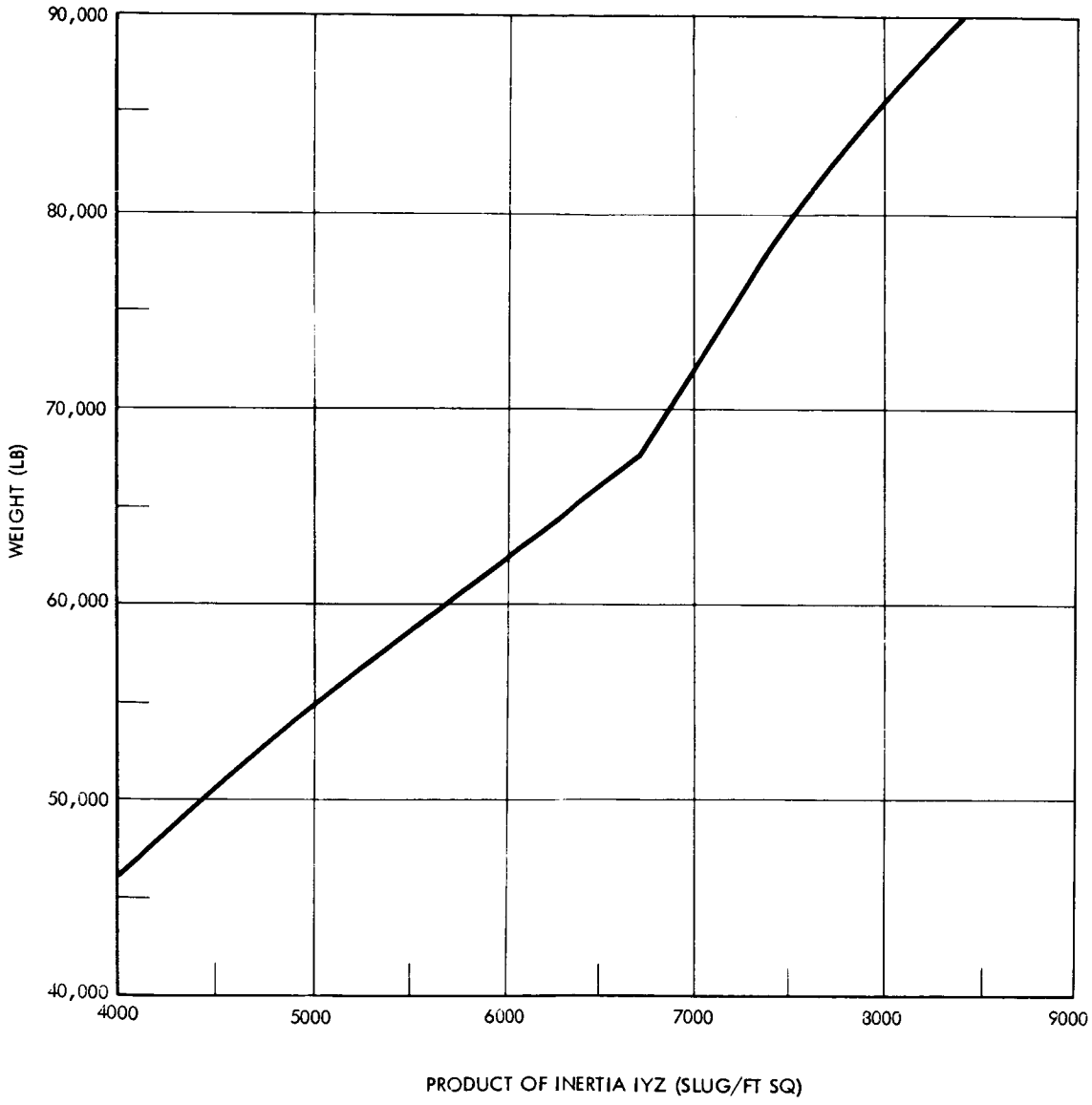


Figure 97. Command Module, Service Module, and Lunar Excursion Module (Sheet 8)

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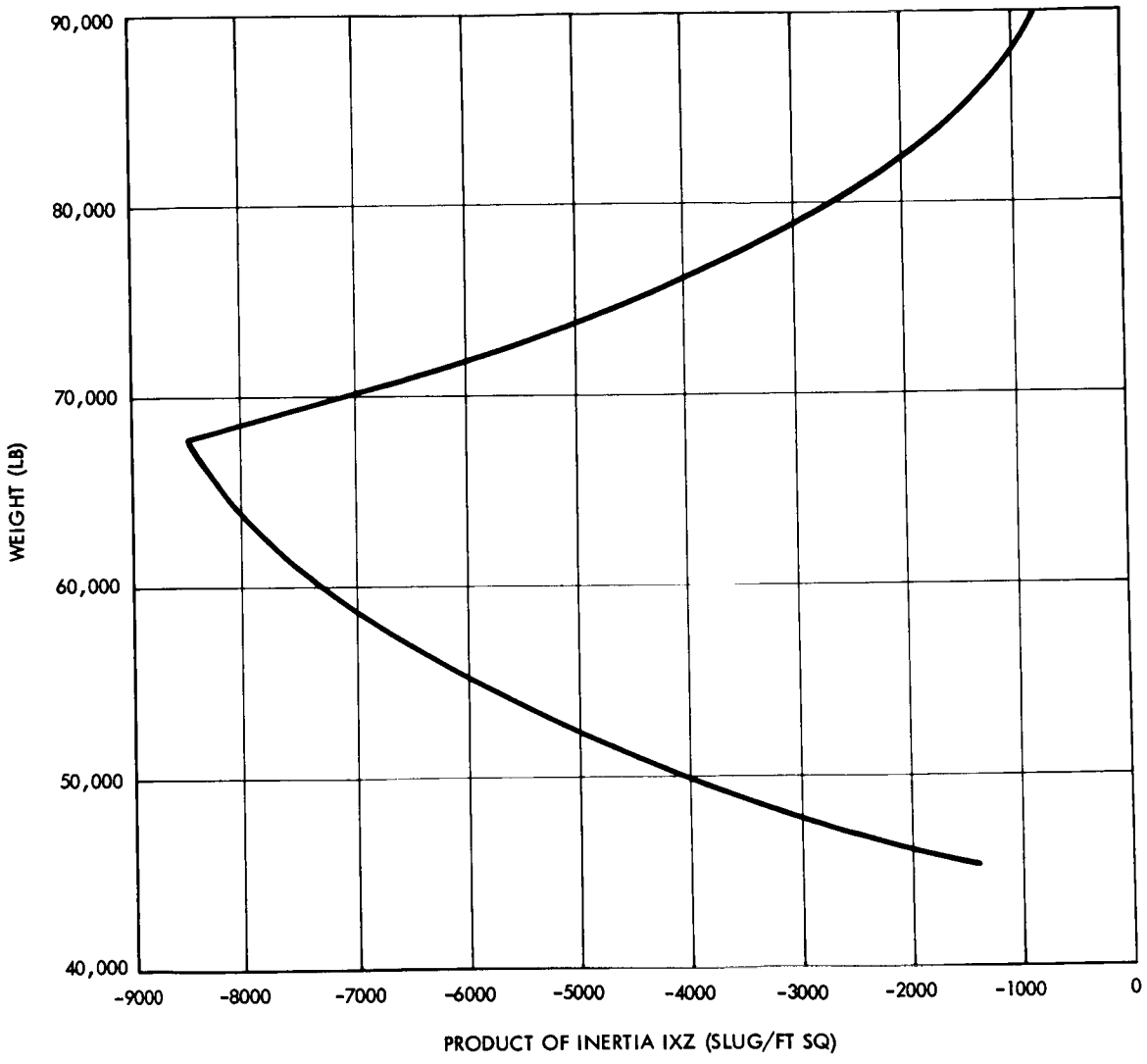


Figure 97. Command Module, Service Module, and Lunar Excursion Module (Sheet 9)

Other studies were of a 220-inch base diameter and various configurations of a 154-inch base diameter. The service module of 154-inch-diameter and 155-inch length contains two equipment bays of 50 degrees each. All equipment is contained therein.

The selected service module configuration reflects the change in mission profile to lunar orbital rendezvous. The present mission-propellant requirement of 45,000 pounds results in a service module bulkhead-to-bulkhead length of 155 inches. The fuel and oxidizer tanks are now of the same length, but with different diameters. A throat-gimbaling engine with the expansion ratio increased to 60:1 was selected for the main propulsion system (Figure 98).

The service module design has been resolved to be a structural-honeycomb shell with an evenly-distributed load at the adapter interface. Six radial beams will accept the command module and tank loads and shear them to the shell structure. The radial beams will be manufactured from aluminum plate using numerical control. Two beams will have honeycomb-shear webs to be bonded in place following machining. The other four will have machined webs and stiffeners to make a tension field beam.

RCS STUDIES

Eleven additional space-allocation RCS and concept studies were completed in the previous quarterly report. These studies for the C-1 are considered for the C-5 and consist of:

1. Seven studies of extendable RCS engines from fairing or equipment bays, and of modular and dual-bottle reliability concepts.

2. Three RCS-engine concepts embodying affixed engines mounted on the service-module shell, and a study of extended engines affixed to booms with engine fairings.

3. Miscellaneous RCS variations of individually-extended or faired engines, affixed to the service module structure extremes.

Space has been allocated in the equipment bays for all the above-noted configurations, including the swing-out modular packages. Figure 99 depicts configurations being considered for RCS engine placement on the service module.

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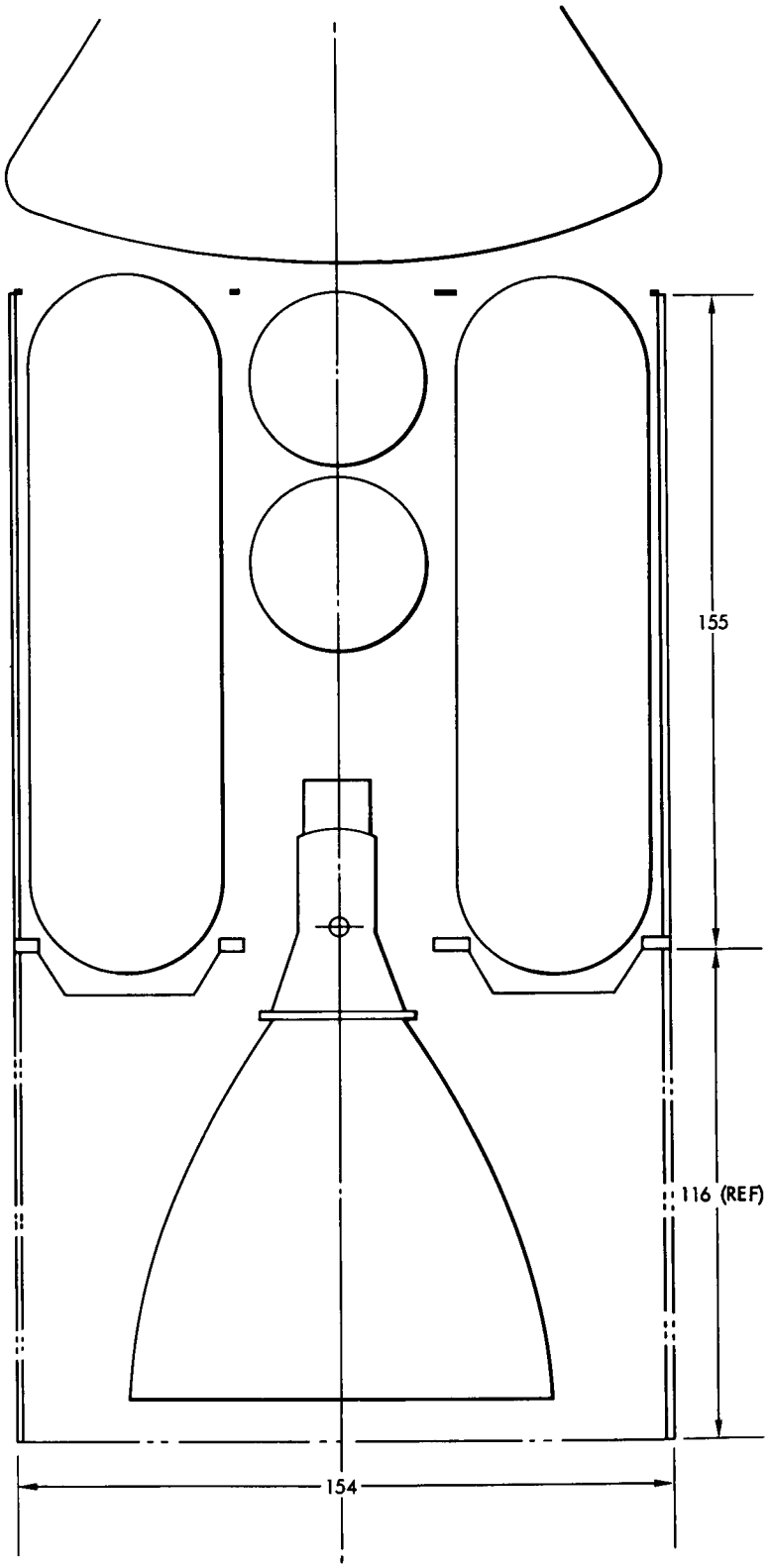


Figure 98. Service Module Throat-Gimbaled System

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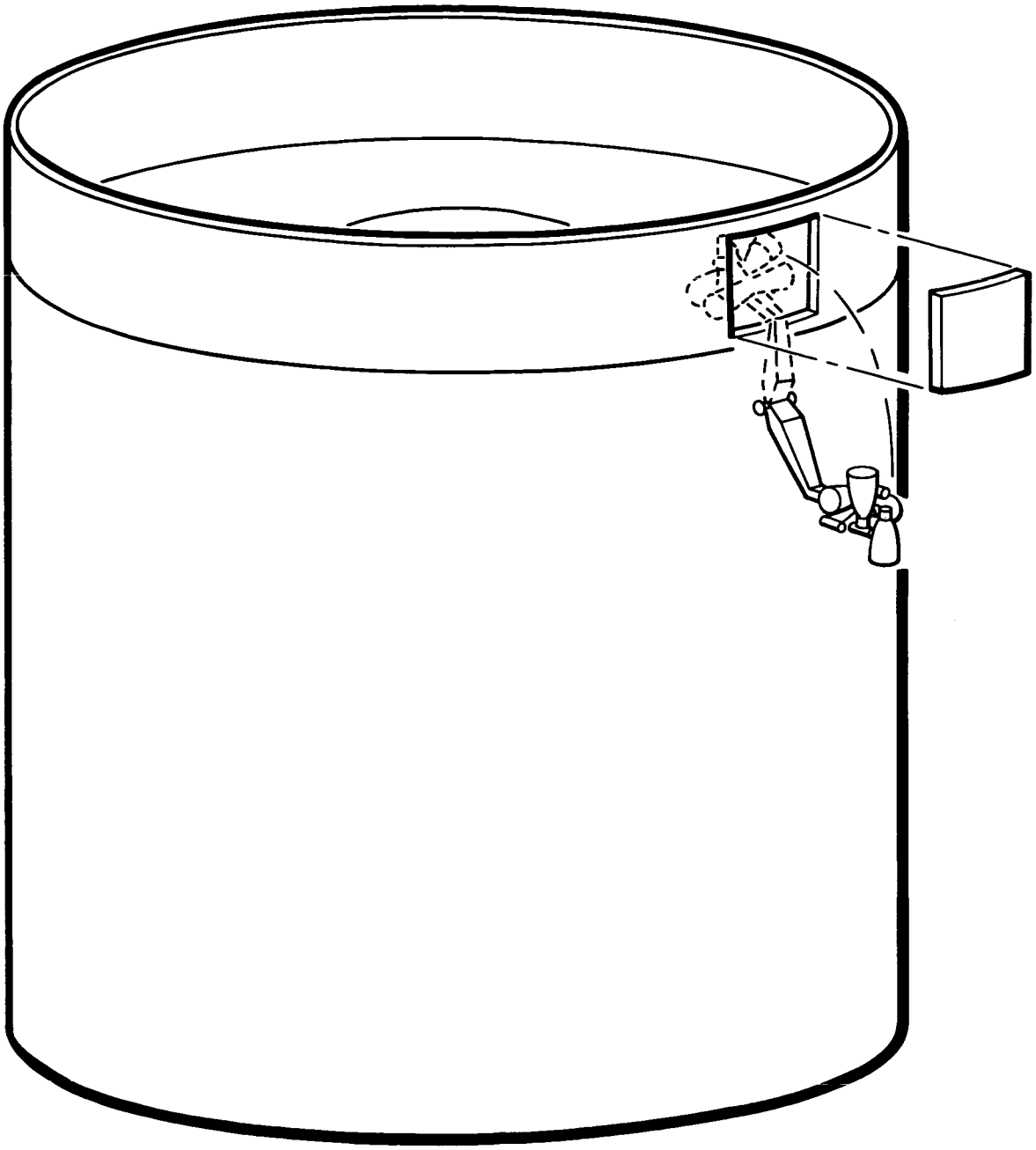

Figure 99. RCS Engine Configurations (Sheet 1 of 3)

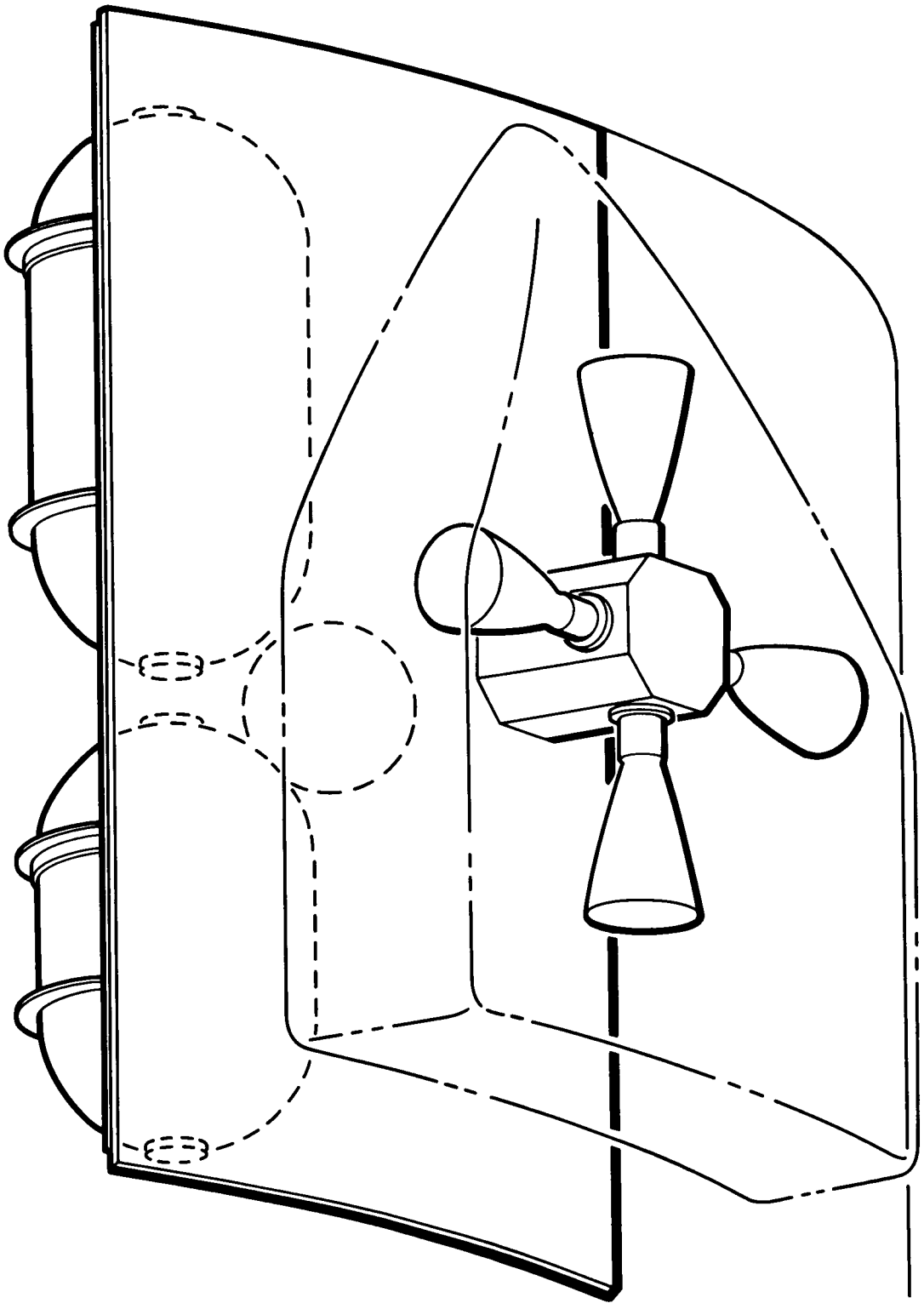

Figure 99. RCS Engine Configurations (Sheet 2 of 3)

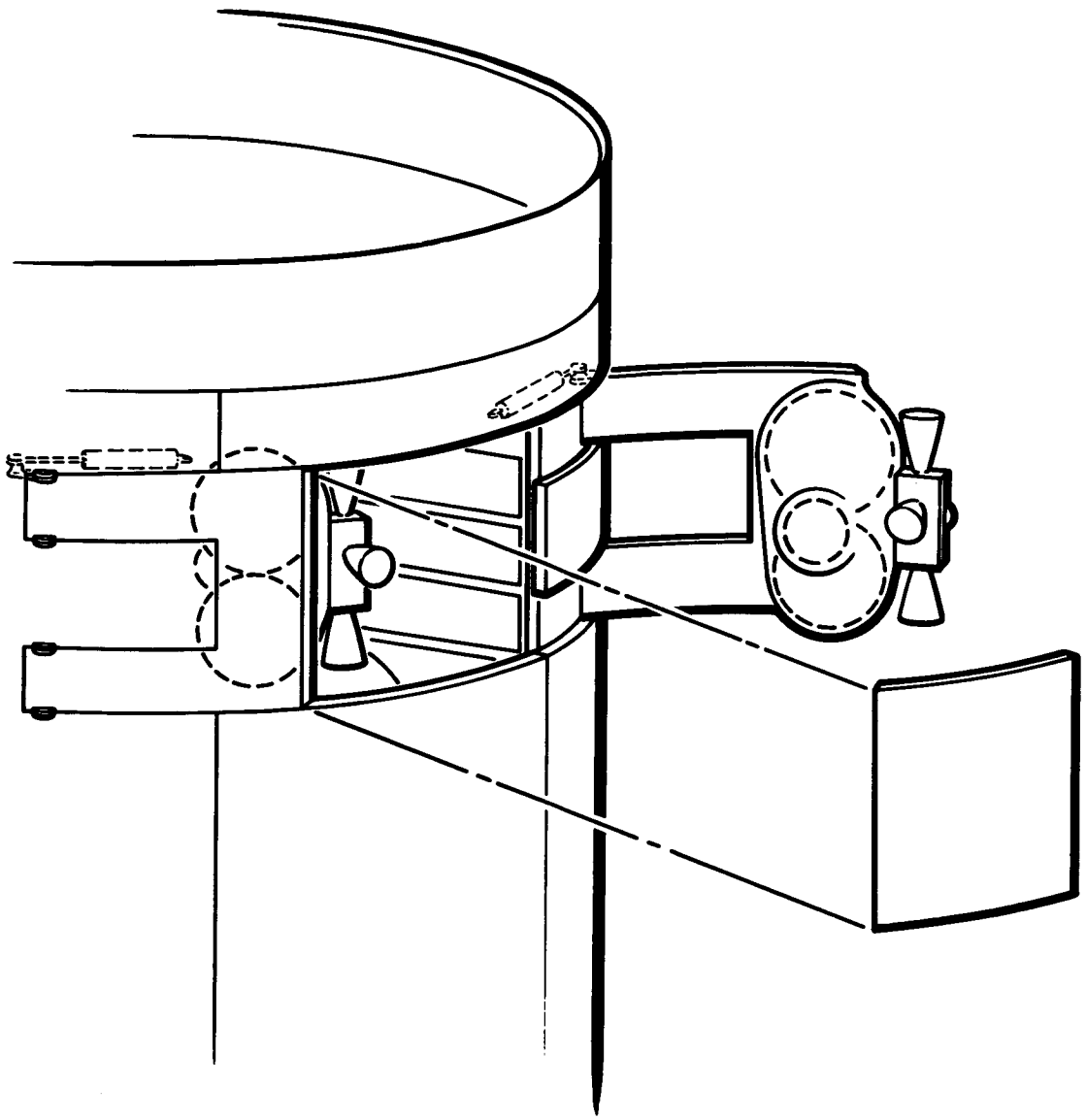

Figure 99. RCS Engine Configurations (Sheet 3 of 3)

Electrical power system and environmental control system radiator locations are undergoing a comparison study for RCS thermal impingement and engine locations, along with a study of structural-honeycomb temperature limits. Among those being evaluated are the locations shown in Figure 100.

LUBRICANTS

A screening program of commercial lubricants and bearing compounds is in progress. This program presently covers only sublimation and degradation of the materials at ultra-high vacuum (10-9 Torr). Additional evaluation studies and a review of a general test program will be discussed in a forthcoming meeting.

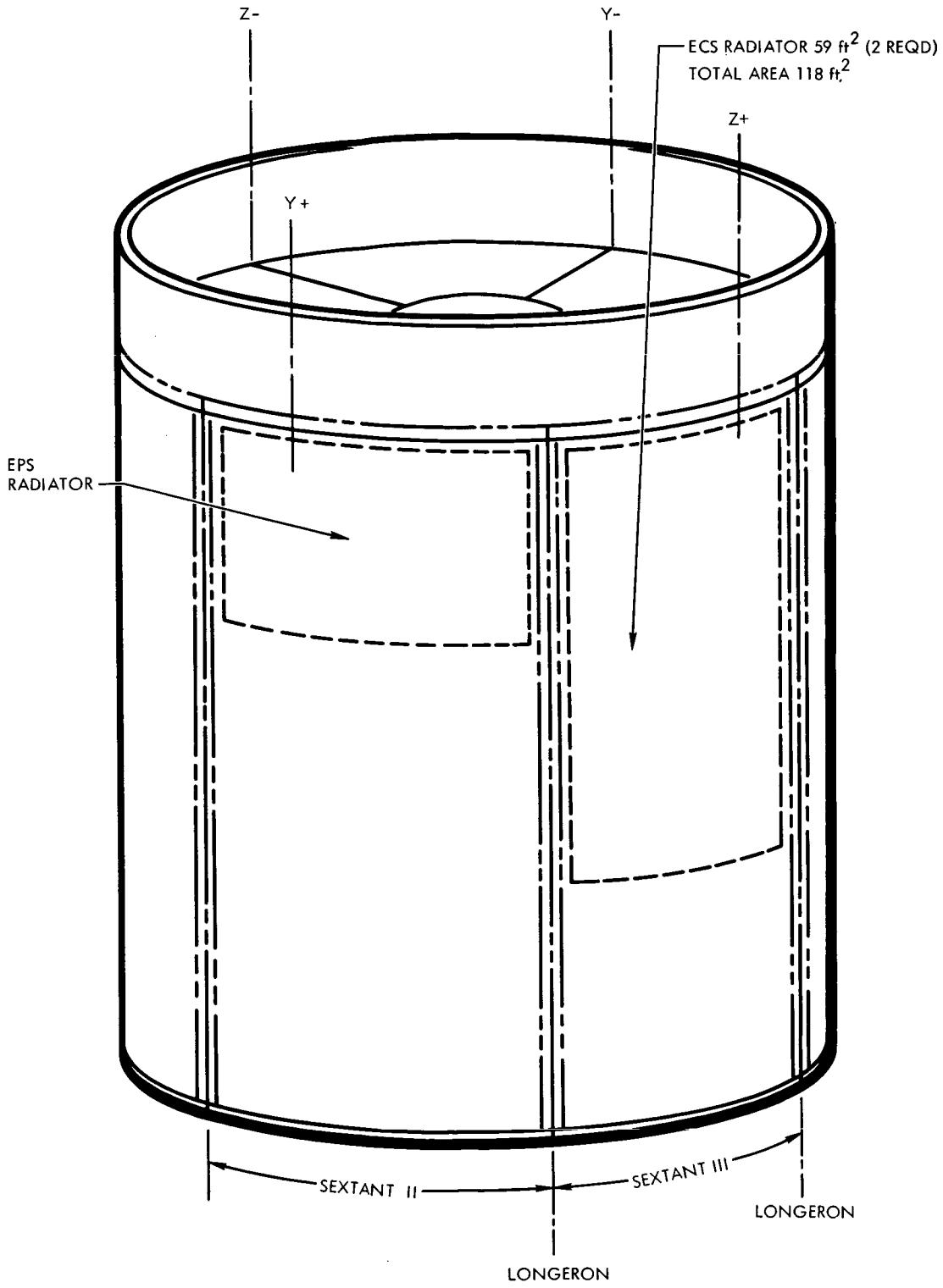


Figure 100. ECS Radiator Locations (Sheet 1 of 3)

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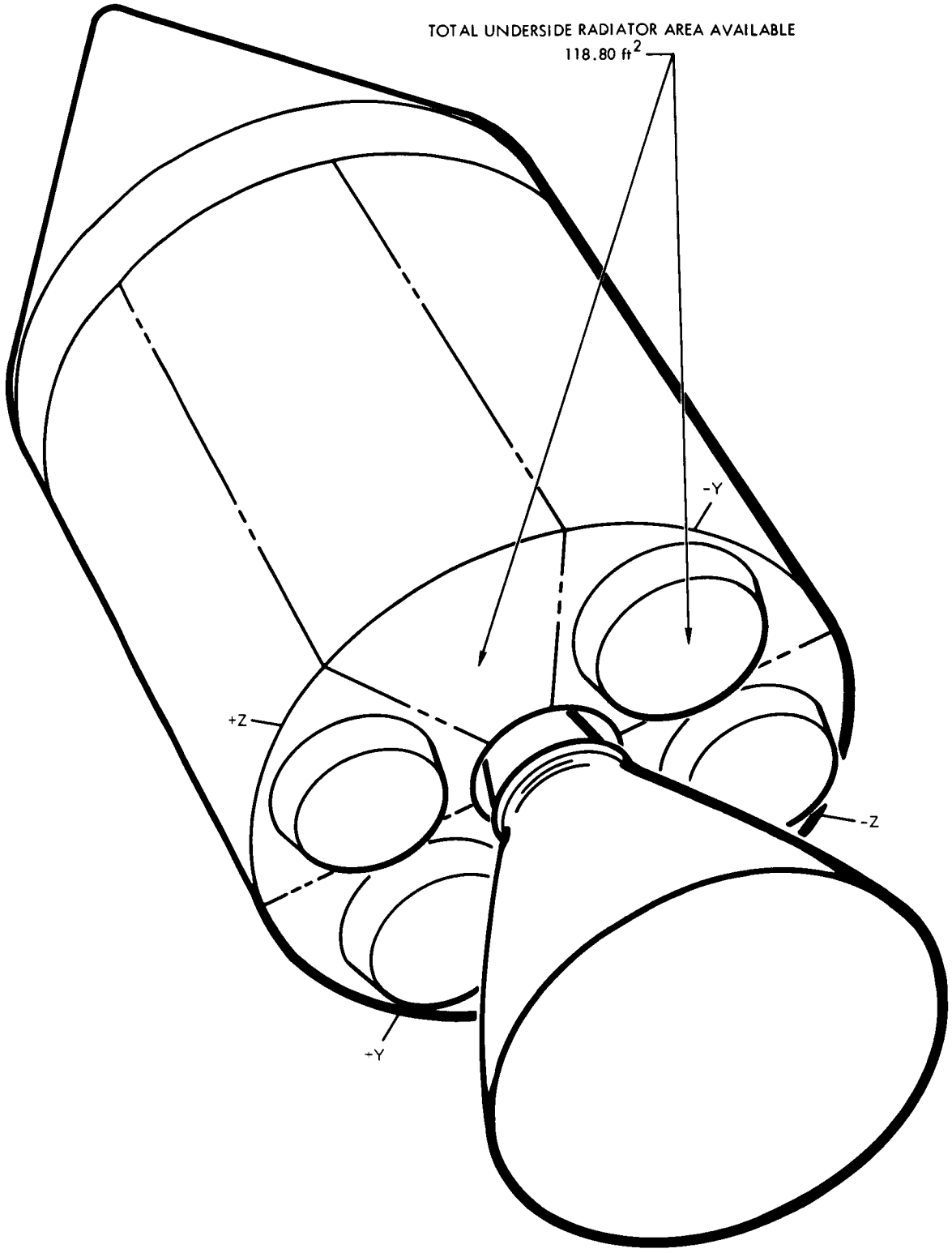


Figure 100. ECS Radiator Locations (Sheet 2 of 3)

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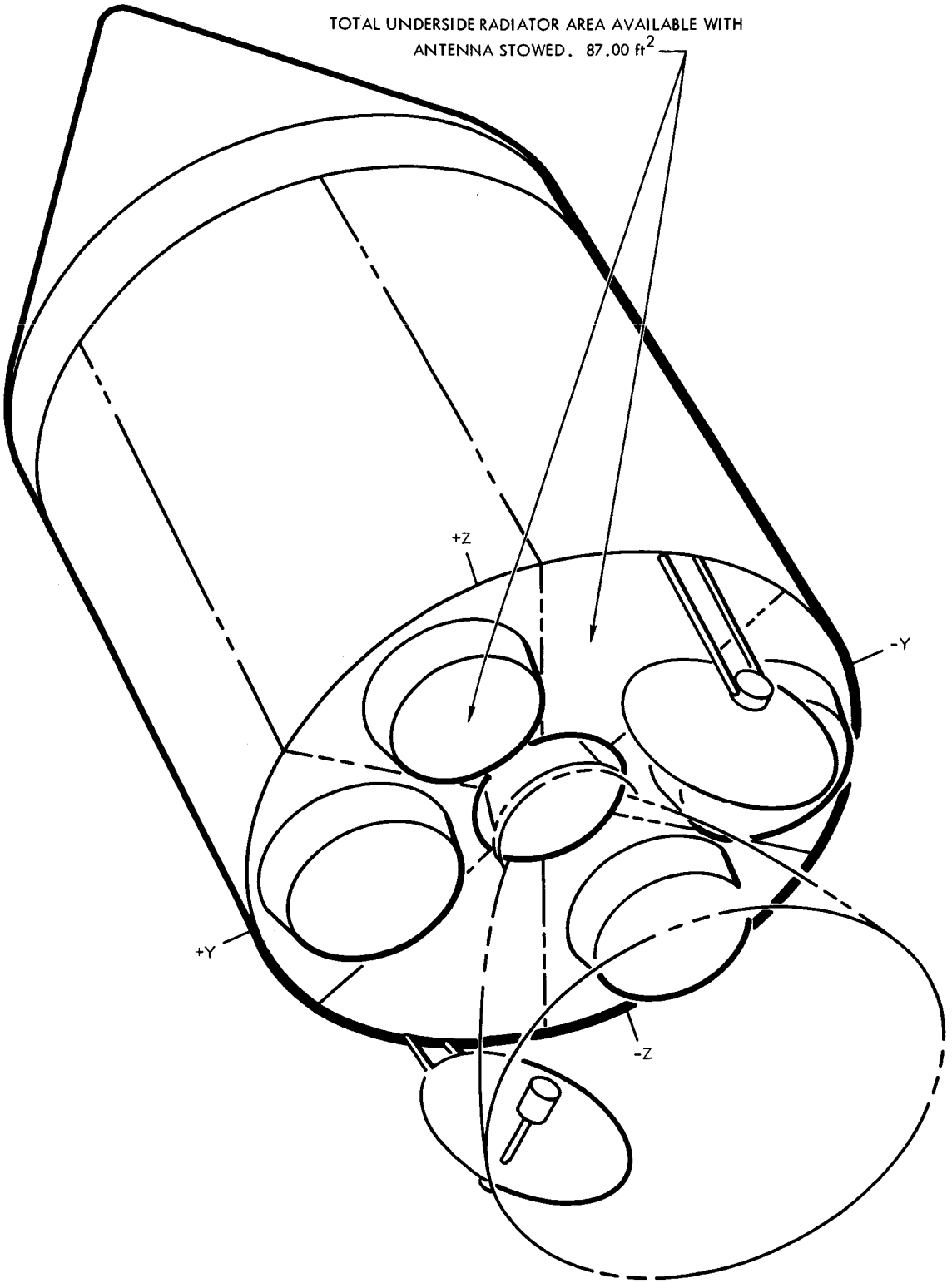


Figure 100. ECS Radiator Locations (Sheet 3 of 3)

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# ELECTRICAL POWER SUBSYSTEMS

## SYSTEMS ANALYSIS AND EVALUATION

### Wiring Techniques

Studies of bonding wires to the outside of the launch escape engine case were completed. The maximum anticipated bundle surface temperature was found to be 450 F. This temperature coincides with the jettison engine ignition function. Tests to develop fabrication techniques will be started during the next reporting period.

### Circuit Protection

Limited circuit-protector testing has disclosed that thermal circuit breakers have to be derated to 70 percent of current capacity for vacuum operation; whereas magnetic types do not require derating. Correlation of the protective-device trip-time characteristic with the wire current-carrying capacity will be determined by tests.

### Floodlighting

In addition to the information included in the last quarterly report regarding temperature and dimming characteristics of fluorescent lighting, a study was made on the weight, volume, and power of a fluorescent system as compared to an incandescent system. It was found that the fluorescent system weighed approximately five times more than the incandescent system (21.62 pounds to 4.45 pounds) and occupied approximately five times more volume (230 cubic inches to 48 cubic inches). The fluorescent system would require approximately 65 watts average for a 14-day mission as compared to 62 watts for an incandescent system. If 28 volts dc is used for the incandescent system, there would be a savings of approximately 15 pounds of inverter weight that would be required for an ac system (fluorescent or incandescent).

Tests are currently being initated to determine heat dissipation characteristics of incandescent lamps while operating in a vacuum. Another study of the vibration and shock characteristics of 28-volt incandescent lamp filaments is being conducted to determine what problem areas may exist if a 28-volt filament incandescent lamp is used.

Umbilical Connectors

One GSE electrical umbilical will be used on the spacecraft and will be located on the service module. A procurement specification will be written.

Two 54-pin umbilicals will be used between the command module and launch escape system (LES) tower. Because heat-shield protection must be provided for the receptacle after tower separation, the ablative material will be bonded to the face of the receptacle, and the plug pins will penetrate through holes in the ablative material. The procurement specification is being prepared.

The command module-to-service module umbilical will penetrate the aft heat shield rather than be located on the side of the command module. There will be two 300-pin receptacles, and critical circuits will be run through both receptacles to increase reliability. The two receptacles will be included in a single installation, but the plugs will be independent of each other. At the time of command module-service module separation, the plug on the command module side of the umbilical will also disconnect to break the heat transfer path into the command module during earth reentry. The procurement specification for this umbilical has been started.

A comparison was made for three different sequencer subsystem circuit philosophies to determine whether the two circuit philosophies suggested by NASA were more feasible than the present configuration.

A study was made of three proposed primary-power distribution circuits that differed according to the number of redundant switches and buses used in each. Results of the analysis indicate that the present configuration is functionally better than the two proposed circuits.

The electromagnetic interference control specification was reviewed. All recommended changes will be incorporated into the specification.

A study was conducted to determine the mathematical relationship between conductive wiring and related variables to minimize the wire weight for each intended function. A machine program is now available to determine the minimum wire weight for specific values of the input parameters.

A Fortran program (AP904) was devised to perform circuit analyses on the IBM-7090 through use of the binomial distribution and the additive law for combining probabilities.

A specification was initiated for the application and testing of electrical bonding on the Apollo spacecraft.

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An investigation was made on grounding and shielding techniques for circuits associated with hazardous devices.

A study is being conducted to analyze the Apollo LES and earth-landing systems (ELS) by means of IBM mission simulation techniques. A cursory analysis of the ELS indicates that the system will perform as planned. Several revisions have been made to both the ELS and LES schematics making it necessary to update the analyses periodically.

The service module-to-command module umbilical-disconnect procurement specification was reviewed for compliance to radio frequency interference requirements.

A study was completed to determine several possible methods for suppressing transients across the relay coils of the LES and ELS sequencers for boilerplate 6.

To determine the best method of wiring hot-wire initiators from the earth landing sequencer, recommendations were made to eliminate the hot-wire firing relays and to run direct wires from the sequencer using twisted shielded pairs. The shield should be multiple grounded to form a barrier, and the circuit wires should be either shorted or open circuited at the sequencer.

## POWER DISTRIBUTION

### Electrical Power System

The battery charger study to optimize the system design and performance was completed. Results show that only one battery charger is necessary. (This charger saves weight by permitting batteries to supplement one fuel cell in the supply of peak loads after loss of two fuel cells without increasing battery capacity to provide for this drain.) A new schematic of the battery control system using a single charger is shown in Figur 10 1.

The electrical load analysis was revised to include the latest load data and mission-operational requirements established to reduce load system energy requirements to a minimum. Load analysis data were used to establish new capacity requirements for the batteries and fuel cells.

Battery proposals were evaluated, a supplier was selected, and NASA verbal approval was obtained. The battery specification was revised to specify a lower capacity (25 ampere-hours), size, and weight. This reduction was made possible by a reduced system load during entry, recovery and postlanding and by a new battery-system operating concept.

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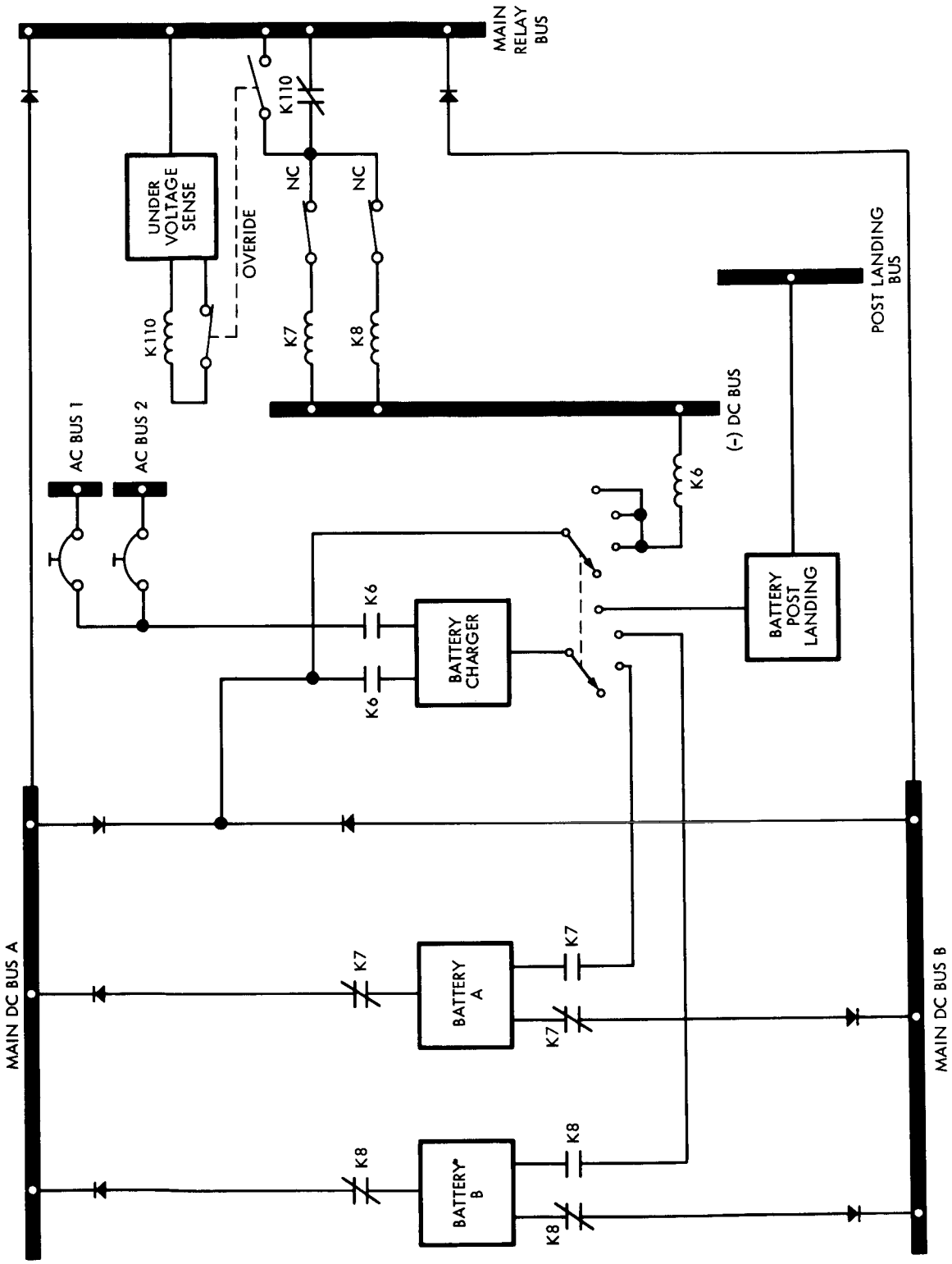


Figure 101. Battery Control System



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This concept is based on using three identical batteries to supply normal loads during the entry, recovery and postlanding periods and two batteries to supply essential loads only during these periods should one battery fail.

The inverter specification was revised to include a higher capacity because of the latest system loads. Other changes included reduced load-imbalance requirements, reduced magnitude of load changes during transient voltage tests, and lower input-voltage transient requirements. This will permit a lighter and simpler inverter design.

A preliminary analysis was begun on inverter failure modes, consequent extremes of voltage and frequency, and the effects of these extremes on a-c loads. Results of this analysis will be used to establish the requirements of the inverter-failure warning system and the requirement for manual or automatic inverter changeover to a standby stage.

The d-c undervoltage control device schematic was completed, a breadboard was completed and successfully tested, and production design is in progress.

Design requirements and development schedules were established for power and control relays. Motor-driven switches are being compared with electromagnetic relays for power transfer applications. Results tentatively show an overall advantage to motor-driven switches.

Pyrotechnics

Various explosive bridge wire initiators and firing units, physical characteristics, development, and qualification status were studied.

The design requirements of sequencers for different vehicles have not been stabilized because of changes in vehicle configurations and operations.

The latest functional requirements and schematic for boilerplate 6 are shown in Figures 102 and 103, for boilerplate 13 in Figures 104 and 105, and for boilerplate 16 in Figures 106 and 107.

## FUEL CELL SYSTEMS

A coordinated study with the fuel cell supplier to analyze fuel cell pump sizes was completed. Because of pressure drop in the coolant lines of the fuel-cell system, it was necessary to increase the size of the fuel-cell pump.

A fuel cell module-equivalent electrical circuit representation was completed. Time-constant and load-sharing characteristics are being studied with this model.

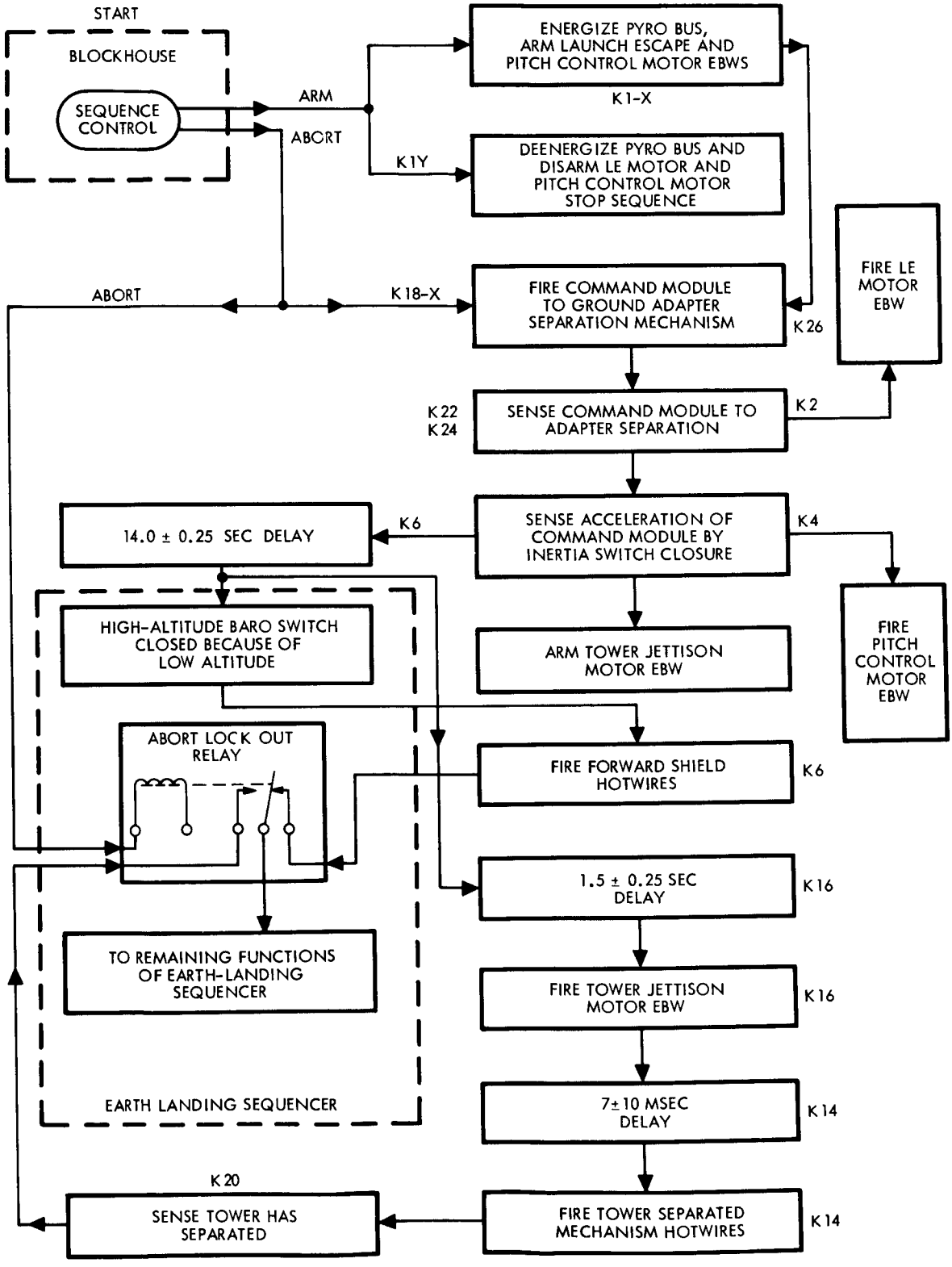


Figure 102. Boilerplate 6 Sequencer Functional Block Diagram

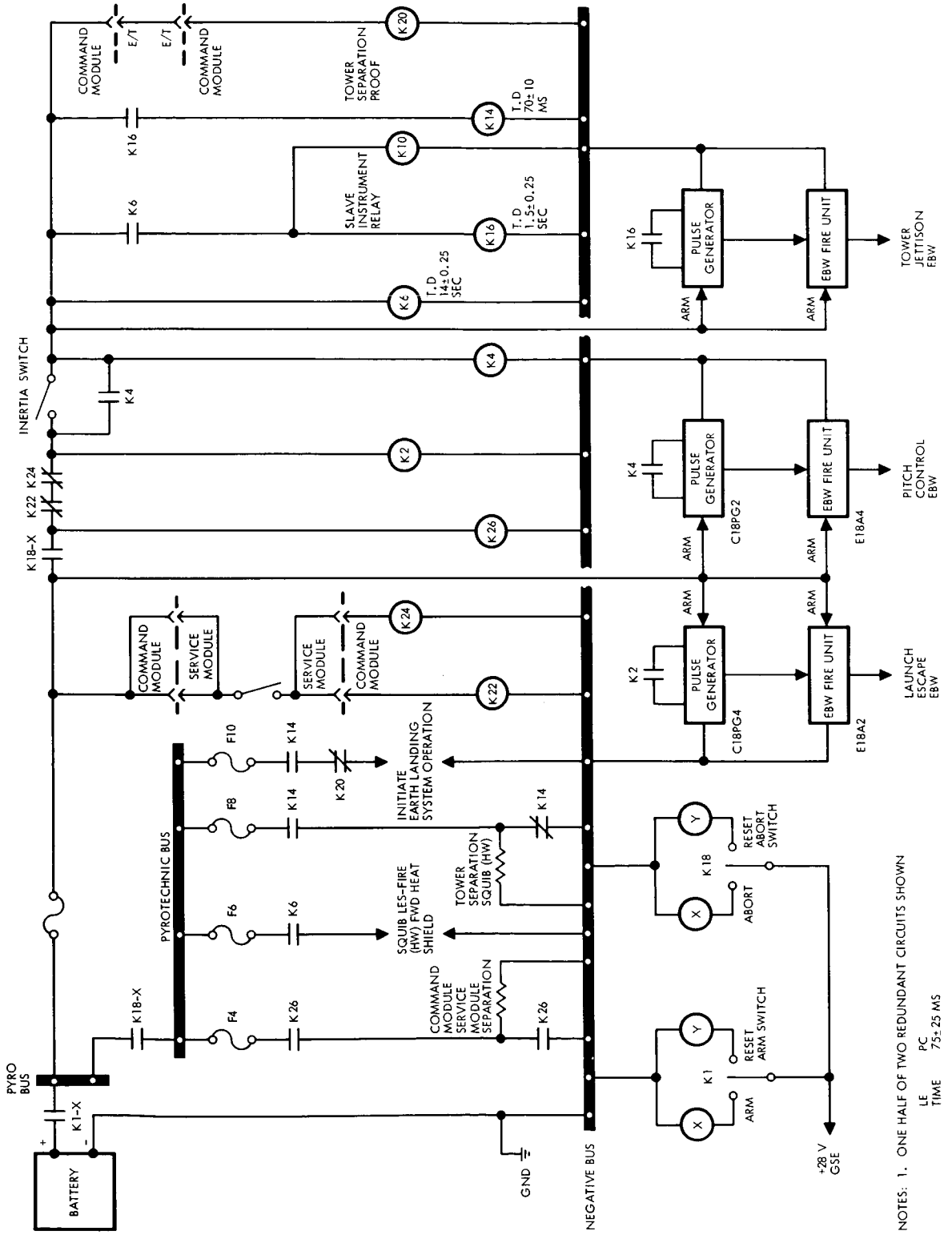


Figure 103. Boilerplate 6 Sequencer Schematic Diagram

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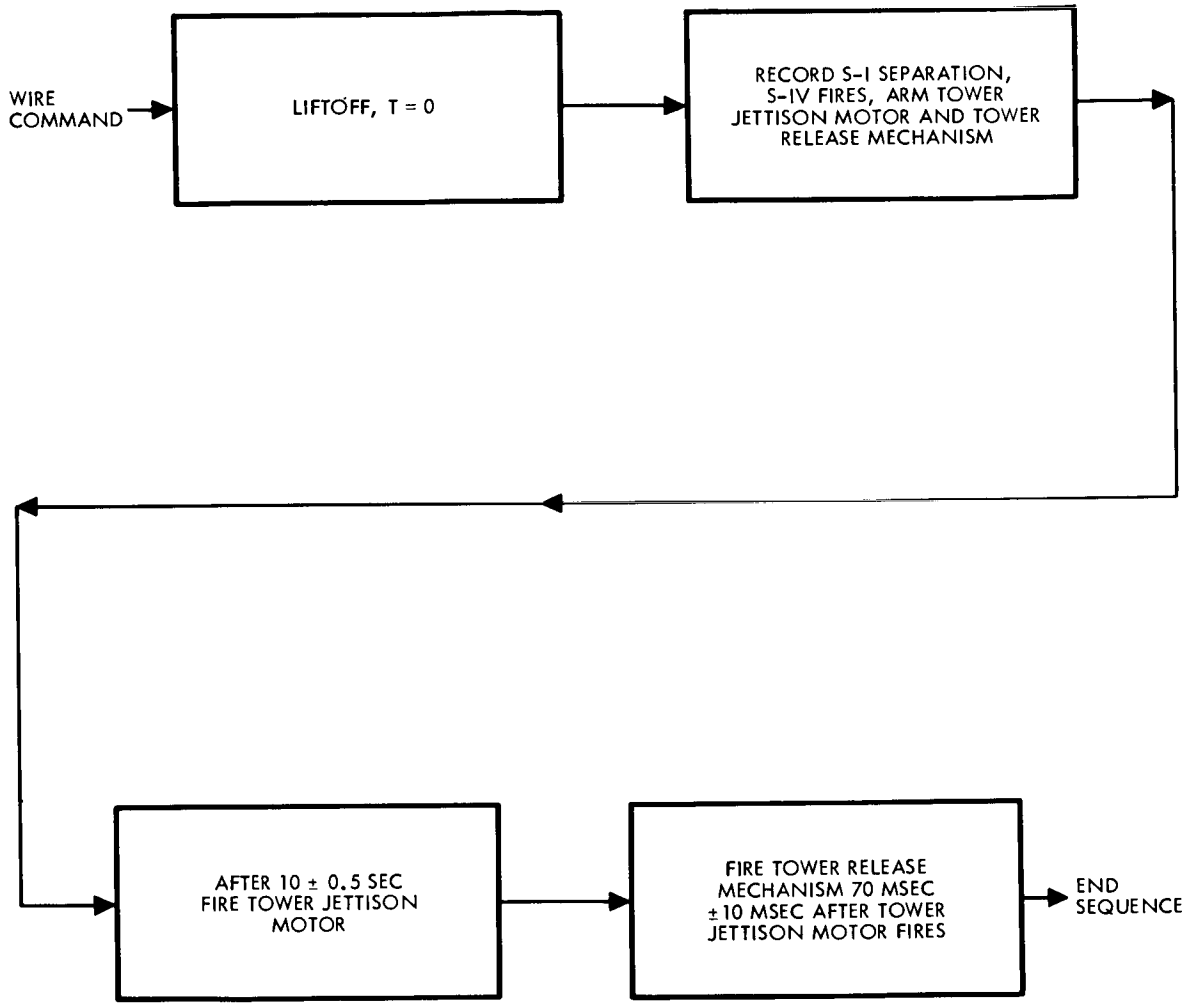


Figure 104. Boilerplate 13 Sequencer Functional Diagram

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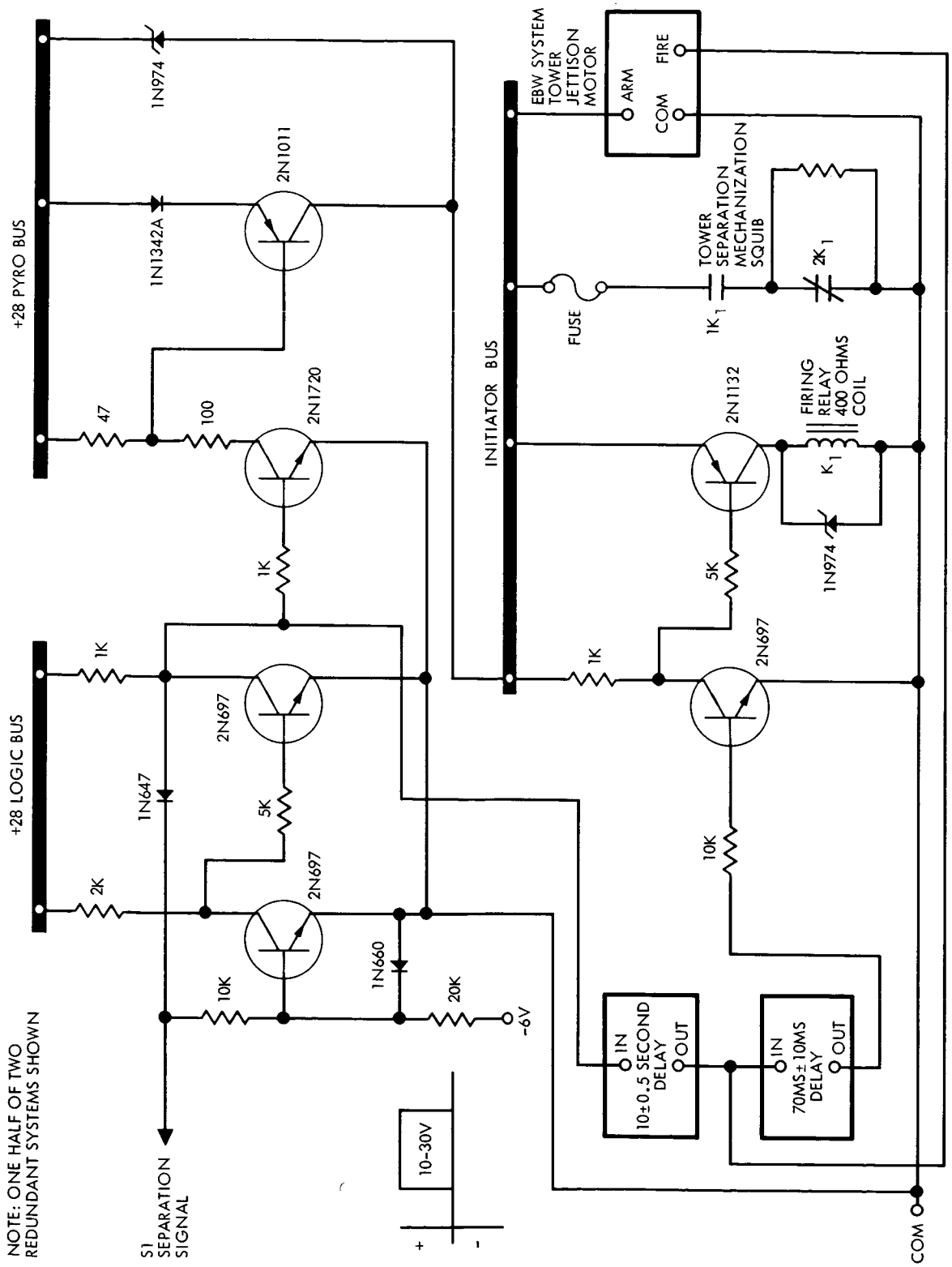


Figure 105. Boilerplate 13 Schematic Diagram



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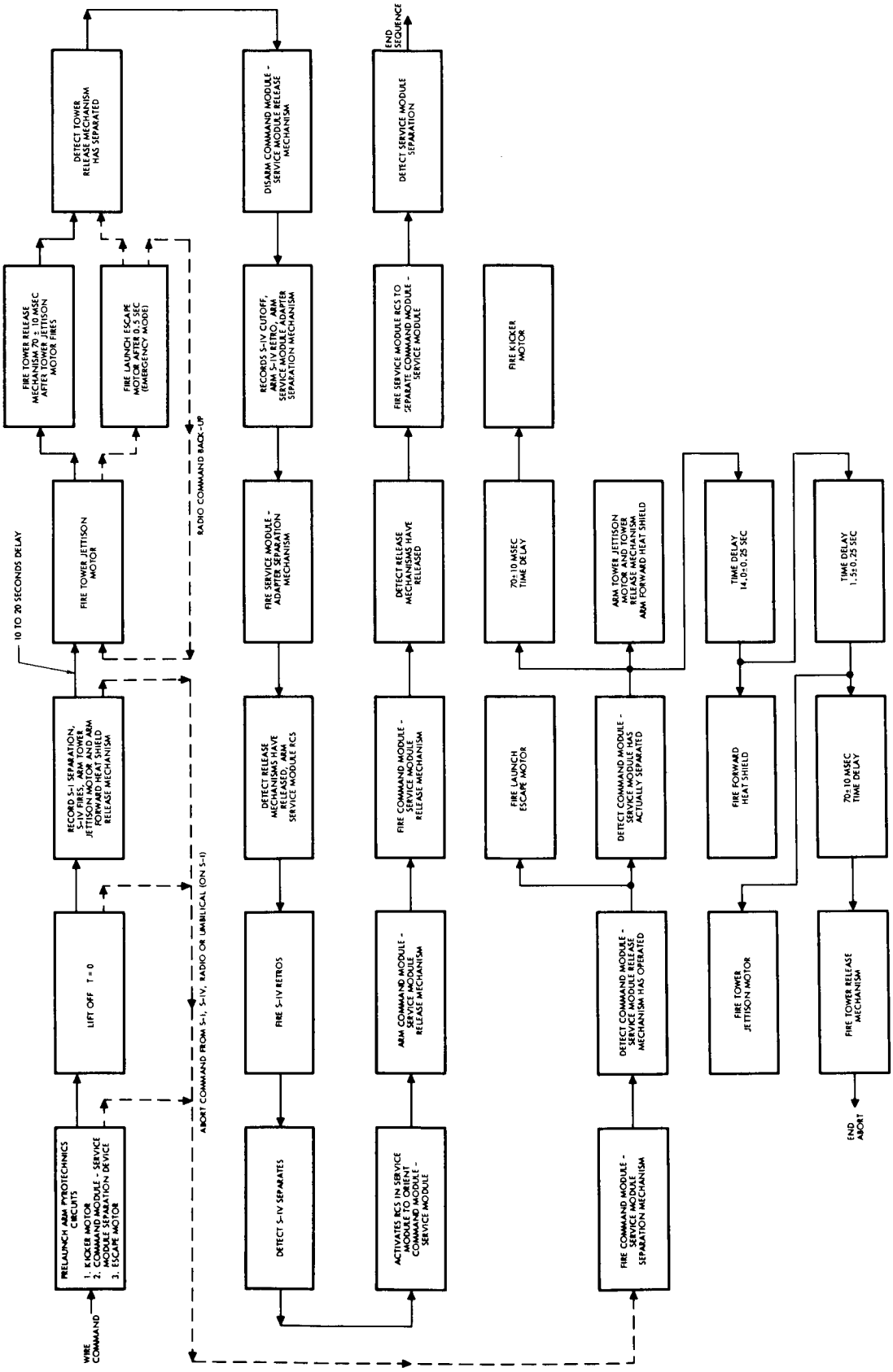


Figure 106. Boilerplate 16 Sequencer Functional Diagram

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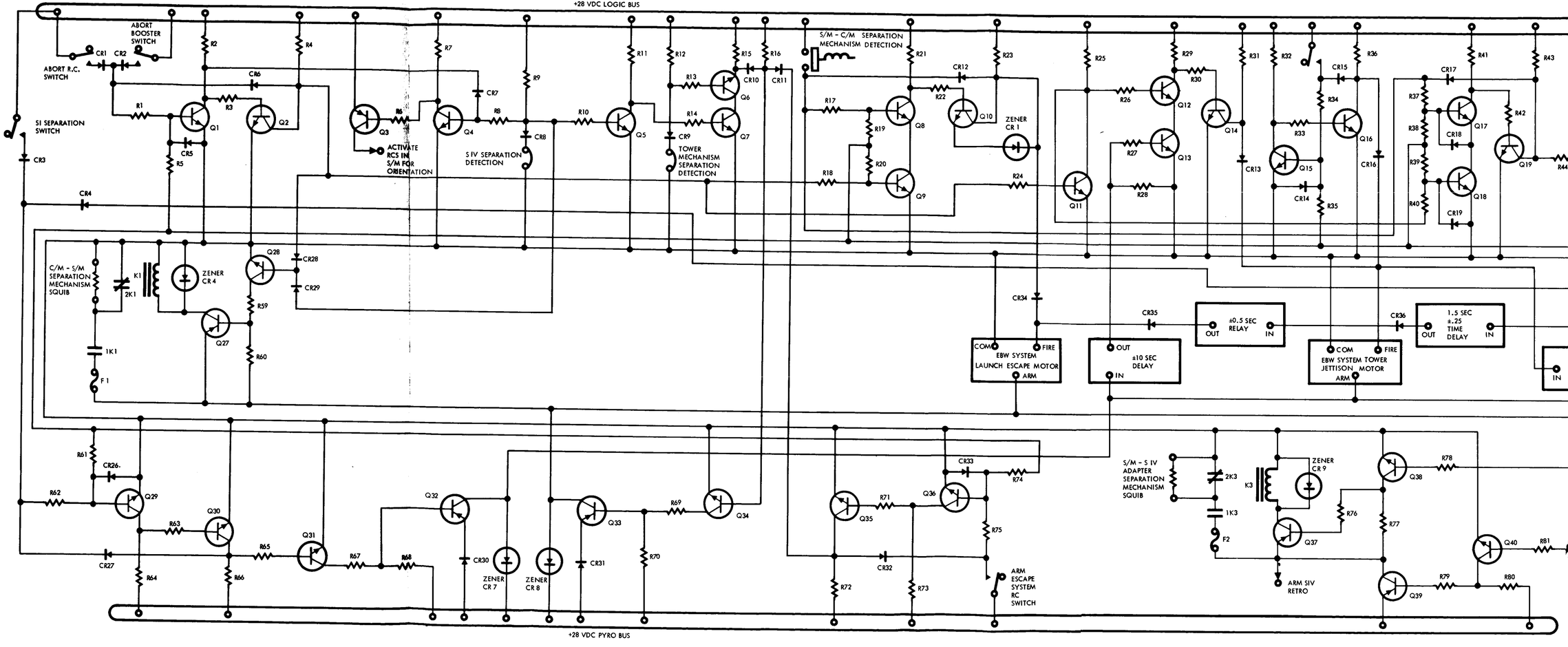
+28 VDC LOGIC BUS
ABORT BOOSTER SWITCH
ABORT R.C. SWITCH
CR1
CR2
SI SEPARATION SWITCH
CR3
CR4
CR5
CR6
R1
R2
R3
R4
R5
Q1
Q2
Q3
Q4
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
CR7
CR8
CR9
CR10
CR11
Q5
Q6
Q7
ACTIVATE RCS IN S/M FOR ORIENTATION
5 IV SEPARATION DETECTION
TOWER MECHANISM SEPARATION DETECTION
S/M - C/M SEPARATION MECHANISM DETECTION
R17
R18
R19
R20
R21
R22
R23
R24
CR12
Q8
Q9
Q10
ZENER CR 1
R25
R26
R27
R28
Q11
Q12
Q13
R29
R30
R31
R32
R33
R34
R35
R36
CR13
CR14
CR15
CR16
Q14
Q15
Q16
R37
R38
R39
R40
R41
R42
R43
R44
CR17
CR18
CR19
Q17
Q18
Q19
C/M - S/M SEPARATION MECHANISM SQUIB
K1
2K1
1K1
F1
ZENER CR 4
Q27
Q28
R59
R60
CR28
CR29
CR34
CR35
CR36
COM
FIRE
EBW SYSTEM LAUNCH ESCAPE MOTOR
ARM
OUT
±10 SEC DELAY
IN
±0.5 SEC RELAY
1.5 SEC ±.25 TIME DELAY
EBW SYSTEM TOWER JETTISON MOTOR
R61
R62
R63
R64
R65
R66
R67
R68
R69
R70
CR26
CR27
Q29
Q30
Q31
Q32
Q33
Q34
CR30
CR31
ZENER CR 7
ZENER CR 8
R71
R72
R73
R74
R75
CR32
CR33
Q35
Q36
ARM ESCAPE SYSTEM RC SWITCH
S/M - S IV ADAPTER SEPARATION MECHANISM SQUIB
2K3
1K3
F2
K3
ZENER CR 9
Q37
R76
R77
R78
Q38
Q39
Q40
R79
R80
R81
ARM SIV RETRO
+28 VDC PYRO BUS

Figure 107. Boilerplate 16 Sequencer Schematic



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INITIATOR AND FIRING UNIT

An agreement was reached with NASA to use the Aerojet General AGX2008 EBW initiator and the General Laboratories 41503-F firing unit for the solid fuel rocket-motor development test programs. All data obtained during development test programs will be inserted in the reliability growth study program.

Firing units being procured from both General Laboratories and Aerojet General will be used in evaluation with quality assurance and reliability test programs at S&ID. The resultant data will be added to the reliability growth study program.

# REACTION CONTROL SYSTEM

## PROPELLANT SYSTEM

Design layout effort is proceeding on the command module reaction control system (RCS) (Figure 108). This configuration, while generally the same as that presented in the preceding quarterly report, incorporated changes to the equipment stress required to approach the currently established reliability apportionment for the system. Items involved include the positive expulsion devices, pressure regulators, and check valves. Although this approach involves a weight penalty, it offers an acceptable compromise in the achievement of apportioned reliability. Other concepts are being studied to obtain the desired reliability goal with smaller weight penalties.

Design layout effort is proceeding on the service module RCS (Figure 109). This configuration has also been updated.

A study is being conducted on an extendable service module RCS package to alleviate the possible problem of radiator heating and surface contamination caused by firing the RCS engines. In the extended position, the engines would be located approximately four feet from the exterior surface. In the retracted position, the engines would be stowed below or within the service module.

## BREADBOARD DEVELOPMENT TESTING

Design of the breadboard oxidizer tanks and fuel tanks was completed. The tanks will be equipped with a rubber bladder as a positive expulsion device.

## RCS BREADBOARD TEST

The fabrication of the command module breadboard is 80 percent complete. The breakdown of the breadboard components and the percentage of their completion are as follows:

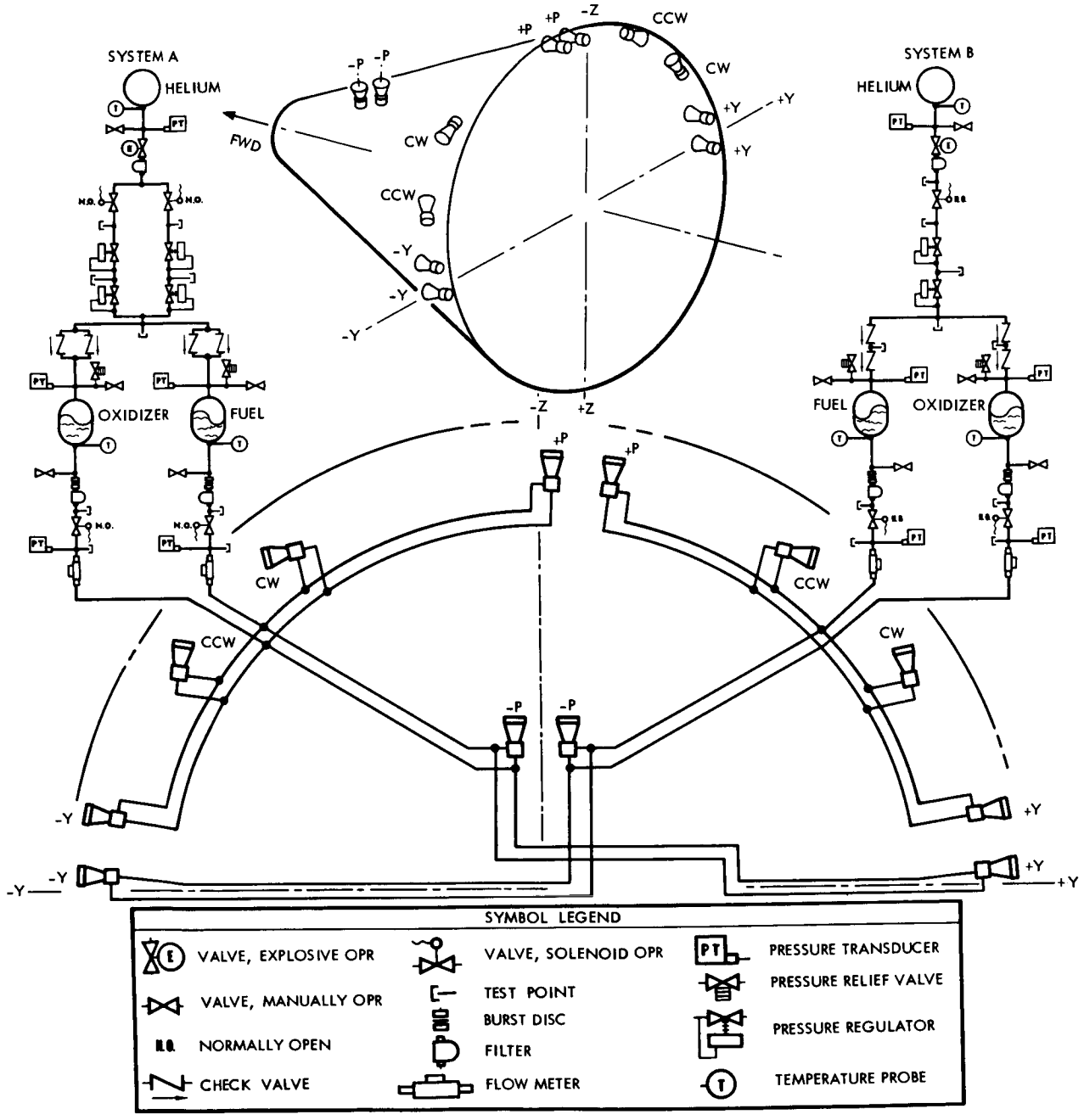


Figure 108. Command Module Reaction Control System

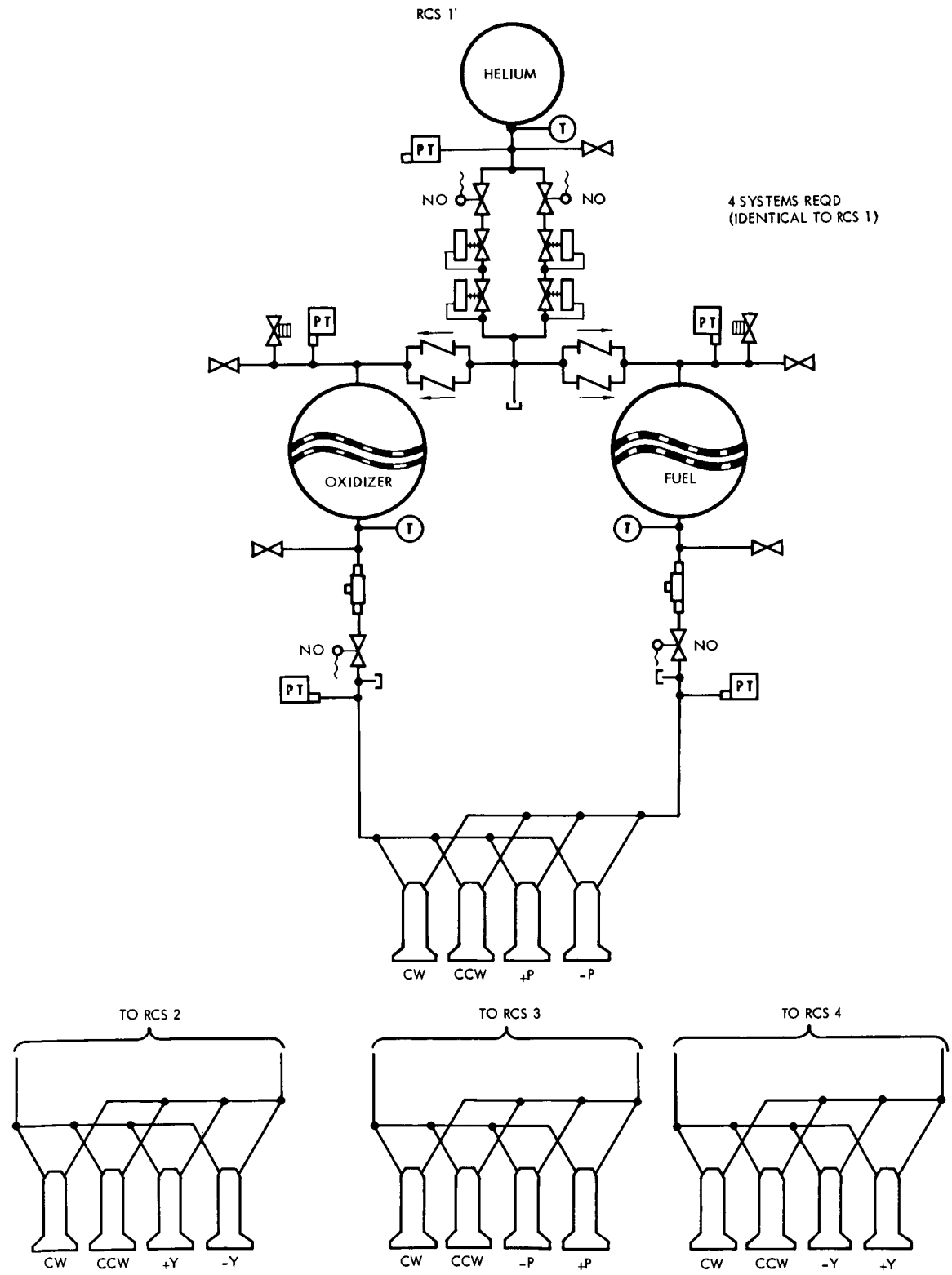


Figure 109. Service Module Quadruple Reaction Control System—Positive Expulsion, No Interconnect

| Component | Percent of Completion |
|---|---|
| Main stand | 100 |
| Inner wall | 100 |
| Outer wall (including doors) | 80 |
| Lower half of RCS compartment | 100 |
| Frames | 100 |
| Parachute compartment support structure | 100 |
| Upper RCS engine support structure | 75 |

The service module RCS breadboard test stand was designed to accommodate the dual-system concept, which required plumbing and components located around the periphery of the service module. Subsequent optimization studies revealed that definite advantages could be gained by changing the dual-system concept to a quadruple-modular concept. Reduction in the size of the test stand can be realized as a result to this change. The system is being redesigned to effect this economy.

## MATERIAL COMPATIBILITY

More than 50 compounded materials have been immersion tested in both nitrogen tetroxide and 50-50 unsymmetrical dimethyl hydrazine/hydrazine. No rubber compound has exhibited satisfactory compatibility with nitrogen tetroxide. The Stillman Rubber Company SR634-70 butyl compound has shown the best compatiblity. The material exhibited a maximum swell of 44 percent, and retained approximately 40 percent of its initial tensile strength after 30 days of nitrogen tetroxide immersion at 70 F. The material is quite permeable to nitrogen tetroxide. Effects of this permeability system operation have not yet been fully evaluated.

A sample has also been exposed to vacuum conditions of $1 \times 10^{-9}$ Torr for over fifty days at room temperature with less than 1 percent weight loss. Immersion, permeability, and other laboratory tests on both slab and O-ring specimens will be continued. Expulsion bladders made from SR634-70 have been ordered for evaluation. Halogenated plastic materials such as Teflon, Aclar, and Tedlar have exhibited excellent compatibility with nitrogen tetroxide but have very poor sealing properties and flexibility.

## COMMAND MODULE ENGINE

The command module RCS system will be modified as shown in Table 18. A dual-coil breadboard driver circuit was recommended on the basis that a substantial electrical power and performance gain could be realized with this model over the single coil value. An investigation to substantiate this recommendation is being conducted.

The driver circuit receives a square-wave command signal for the stabilization and control (SCS) equipment. It then energizes the hold coil which, in turn, causes an induced voltage in the pull-in coil. This induced voltage is then utilized to energize the pull-in circuit. The limit network senses the current rise in the pull-in coil and switches it off at a predetermined value. The hold coil remains energized until termination of the square-wave command signal.

The redundant coil will be electrically and physically separated from the pull-in and hold-in coils, and will be controlled directly by the spacecraft pilot.

A potential savings may be realized if the roll-and-yaw engine thrusts vectors are oriented about the stability axis, in lieu of the present orientation about the geometric axis. Preliminary estimates indicate that the propellant savings may be as much as 30 percent. An installation layout is being drafted showing the desired locations and determining the effective moment arms. A study will be conducted on the Apollo flight simulator to substantiate the propellant savings. This study will compare the total impulse requirements necessary to effect a controlled rate command when the two different installations are employed.

Information is being collected toward defining a duty cycle for the command module rocket engines. The duty cycle will be formulated from data obtained during simulator reentry flights, utilizing inputs to the stability and control closed-loop system.

Table 18. System Design and Performance Changes Utilizing Modified Gemini SE-7 Engine Command Module RCS

| Item | Present | Former |
|---|---|---|
| Engine | Modified Gemini SE-7 (540 sec life) | TMC cold wall engine |
| Reliable life | 200 seconds | 600 seconds |
| Weight | 8.5 pounds | 5.5 pounds |
| Propellant | MMH/N204 | Aerozine 50/$N_2O_4$ |
| System pressure | | |
| Static | 295 psia | 190 psia |
| Dynamic | 280 psia | 170 psia |
| Equilibrium wall temperature | 400 F | 200 F |
| Minimum impulse | 2 pound-seconds | 1 pound-second |
| Response time (miscellaneous) | | |
| Electrical "on" to 90 percent thrust | 24 milliseconds | 12.5 milliseconds |
| Electrical "off" to 5 percent thrust | 17.5 milliseconds | 12.5 milliseconds |
| Propellant system weight change | 14 pounds | 0 |
| Additional System Changes | | |
| Redesign nozzle extensions | | |
| Added logistics required to handle MMH | | |

Four additional engines were added for AEDC testing. The delivery schedule was updated to reflect the latest master phasing schedule, which deleted the requirements for command module engines on boilerplates 16 and 18. The subcontractor anticipates no problem in meeting the delivery schedule.

## SERVICE MODULE ENGINE

A preliminary duty cycle was formulated for the service module reaction control engines. It would be used in the determination of engine design requirements and for the establishment of engine qualification test procedures.

Due to a requirement for accomplishing navigational sightings throughout the spacecraft-design mission, the engine minimum impluse will be reduced to a maximum of 0.6 pounds per second. A preliminary analysis of the current engine configuration has indicated that the engine is capable of achieving a nominal minimum impulse of 0.5 pounds per second. Further studies are under way to determine the variations of minimum impulse that can be expected under actual operating conditions.

Two endurance tests of 100,000 cycles each were conducted on two solenoid-valve seat assemblies. The first seat assembly demonstrated a maximum nitrogen tetroxide leakage of 1.1 cubic centimeters per hour (acceptable) during tests, and the second seat assembly demonstrated zero leakage during the 100,000 cycles.

Meteoroid flux, velocity spectrum, and techniques for estimating damage were reviewed with the subcontractor. The probability of a hit, the amount of damage caused, the effect of this damage on the mission, and the weight or complexity of protection methods are uncertain at this time.

The first Apollo engine equipped with an altitude nozzle was operated at reduced performance in an altitude environment. Test results indicated that heat transfer from the combustion chamber to the injector head was consistent with the results attained with the 25-pound thrust Advent engines.

Various injector configurations were evaluated. As a result, the prototype engine configuration has been frozen with an 8-on-8 multiple doublet injector.

## FACILITIES

Instrumentation requirements have been established for both flight test and for the WSMR operations.

A preliminary plan outlining test requirements for both the F-2 facility and AFRM 001 at WSMR was prepared.

Temporary facilities for the extensive impact testing required are being readied for use in the program. Effects of nitrogen tetroxide on 6Al-4V titanium alloy will be determined.

# GROUND OPERATIONAL SUPPORT SYSTEM (GOSS)

The lunar landing mission was analyzed to establish the required information flow from the spacecraft to the GOSS network. The over-all criterion for required information is the necessity to increase mission success and crew safety probability.

A study was initiated during this period to establish the GOSS coverage requirements for the parking orbit, the injection into translunar phase, the early part of the translunar phase (to 30,000 nautical miles), the latter part of the transearth phase (from 30,000 nautical miles), and the entry phase. The study is concentrated on the near-earth GOSS stations coverage of the parking orbit and the injection phase and the DSIF stations coverage of the early part of the translunar phase in the event of injection near Hawaii.

The work statement for the reflectivity study is in preparation. This study will provide data to enable evaluation of radar skin tracking capabilities. The results of the communications reentry blackout study will be incorporated in the work statement.

The general development plans for the SCATLAB were completed. Location and space requirements were considered for the fixed facilities, and trailer requirements were considered for the mobile facility.

The ionizing radiation from a solar proton event would expose the spacecraft to the greatest concentration of harmful radiation, and it was found that if the absorbed dose for the crew did not exceed the emergency limit (100 rem), Kodak SO-243 Aerographic Film can be used with no additional shielding or other safety precautions. The lag caused by the ionizing radiation will not seriously interfere with the resolution or sensitivity of the film. If other types of films are used or if a greater amount of radiation is encountered, additional shielding or other precautions, such as onboard processing, will be necessary.

# Table A-1. Apollo Schedule of Meetings and Trips

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| JULY | | | | |
| Radiocommunications analysis | Cedar Rapids, Iowa | 1-5 July | Downs<br>Pope<br>Butler<br>Alpaugh | S&ID, Collins |
| TV evaluation and demonstration | Cedar Rapids, Iowa | 1-27 July | Green | S&ID, Collins |
| Heat shield analysis | Wilmington, Massachusetts | 2 July | Hanifin<br>Stone<br>Morrant<br>Lundgren | S&ID, Avco |
| Electrical systems panel | Houston, Texas | 2-3 July | Champaign<br>DeVanzo<br>Divvens | S&ID, NASA |
| Lunar module interface coordination | Houston, Texas | 2-3 July | Moote | S&ID, NASA |
| Little Joe II Saturn booster coordination | Houston, Texas | 2-3 July | Gatewood | S&ID, NASA |
| Biweekly crew systems | Houston, Texas | 5-6 July | Tarr<br>Hair | S&ID, NASA |
| Crew equipment discussion | Houston, Texas | 5-6 July | Dewitt | S&ID, NASA |
| Simulation program discussion | Houston, Texas | 5-6 July | Steiner | S&ID, NASA, and Minneapolis-Honeywell |
| Guidance and control biweekly meeting | Houston, Texas | 5-7 July | McNerney<br>Stone<br>Levine | S&ID, NASA |
| Biweekly design review | Houston, Texas | 5-7 July | Antletz | S&ID, NASA |
| Wind tunnel test conference | Mountain View, California | 6 July | Allen<br>Snowden | S&ID, Ames |
| Biweekly crew systems | San Antonio, Texas | 7-12 July | Hair | S&ID, SAM |
| Wind tunnel tests | Tullahoma, Tennessee | 8-12 July | Schurr<br>Biss | S&ID, NASA |
| Wind tunnel facilities inspection | Minneapolis, Minnesota | 9 July | Bornemann | S&ID, Fluidyne Corporation |
| Stanford and Kraft Food evaluation | Menlo Park, California<br>San Francisco, California | 9-10 July | Voss | S&ID, Stanford, and Kraft |
| Exhaust plume experiments and plume testing | Hampton, Virginia<br>Houston, Texas | 9-12 July | Piesik | S&ID, NASA |
| Technical representative resident representation | Hartford, Connecticut | 9-13 July | Synder | S&ID, Pratt and Whitney |
| Design criteria discussion | Huntsville, Alabama | 9-13 July | Gycel<br>Robinson | S&ID, NASA |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| GSE coordination | Minneapolis, Minnesota | 9-10 July | Gibson | S&ID, Minneapolis-Honeywell |
| GSE checkout | Houston, Texas | 10-11 July | Mier<br>Triman<br>Alpert<br>Garder | S&ID, NASA |
| Display and controls, GSE | Cambridge, Massachusetts | 10-13 July | Todd<br>Gardner<br>Williamson<br>Cramer | S&ID, MIT |
| Documentation coordination | Van Nuys, California | 11 July | Eggert | S&ID, Northrop-Ventura |
| Apollo WSMR coordination | Las Cruces, New Mexico<br>El Paso, Texas | 11-12 July | Rogers | S&ID, NASA |
| Heat shield design review | Houston, Texas | 11-12 July | Cook<br>Hanifin<br>Lundgren<br>Greshun | S&ID, NASA |
| Western simulation council | Seattle, Washington | 11-13 July | Furlong | Symposium |
| Simulation and coordination | Columbus, Ohio | 11-13 July | Hart | S&ID, NAA-Columbus |
| Navigation and guidance coordination | Cambridge, Massachusetts | 11-13 July | Kennedy<br>Zeitlan<br>Le Rose<br>Latino | S&ID, MIT |
| GSE exchange data, testing and updating discussion | Cambridge, Massachusetts | 11-20 July | Morland | S&ID, MIT |
| Systems test and checkout | Cambridge, Massachusetts | 11-14 July | Gilio | S&ID, MIT |
| Wind tunnel test discussion | Houston, Texas | 12 July | Field | S&ID, NASA |
| Field facilities analysis | El Paso, Texas | 12-13 July | Young | S&ID, Northrop-Ventura |
| Crew safety, mission, and navigation reliability success | Houston, Texas | 12-13 July | Jones<br>Myers<br>Fatton | S&ID, NASA |
| R&D integration coordination | Houston, Texas | 12-27 July | Wilkens | S&ID, NASA |
| Lunar landing simulation review | Hampton, Virginia<br>Columbus, Ohio | 12-25 July | Oglevie | S&ID, NASA |
| Facilities coordination | Houston, Texas | 15-19 July | Mundy | S&ID, NASA |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| R&D instrumentation | Houston, Texas | 15-20 July | Barmore<br>Nault<br>Beeson | S&ID, NASA |
| Wind tunnel tests | Tullahoma, Tennessee | 15 July-8 August | Gillies<br>Lundy | S&ID, NASA |
| Monthly schedule coordination | Wilmington, Massachusetts | 16 July | Feltz<br>McCarthy<br>Kinsler | S&ID, Avco |
| High-energy farming problems discussion | Canoga Park, California | 16 July | Salvador | S&ID, Rocketdyne |
| Heat shield analysis | Wilmington, Massachusetts | 16-17 July | Hanifin<br>Skene | S&ID, Avco |
| Task trainers | Houston, Texas | 16-18 July | Benefield<br>Smith<br>Neff | S&ID, NASA |
| Fuel cell systems | Hartford, Connecticut | 16-19 July | Nash | S&ID, Pratt and Whitney |
| GSE computer checkout | Houston, Texas<br>Minneapolis, Minnesota<br>Boston, Massachusetts | 16-19 July | Stratton<br>McMillan | S&ID, NASA, and Minneapolis-Honeywell |
| Wind tunnel tests | Mountain View, California | 16-21 July | Snowden<br>Sola<br>Davis | S&ID, Ames |
| Navigation and guidance | Cambridge, Massachusetts | 16-20 July | Beck<br>Kennedy | S&ID, MIT |
| GSE crew performance | Minneapolis, Minnesota<br>Cedar Rapids, Iowa | 16-21 July | Boehleke<br>Hartman | S&ID, NASA, Minneapolis-Honeywell, Collins |
| American Rocket Society Lunar Missions Meetings | Cleveland, Ohio | 16-22 July | Carter<br>Wells<br>Ryker<br>Oglevie | Symposium |
| Progress report | Cambridge, Massachusetts | 17-18 July | Beck<br>Anaya | S&ID, NASA, and MIT |
| Instrumentation coordination | Concord, California | 17-18 July | Dunham | S&ID |
| Collier Trophy presentation | Washington, D.C. | 17-19 July | Feltz<br>Crossfield | S&ID, President |
| Task analysis data display | Minneapolis, Minnesota | 17-19 July | Morris | S&ID, Minneapolis-Honeywell |
| Preliminary flight control analysis | Minneapolis, Minnesota | 17-20 July | Codding<br>Bagley | S&ID, Minneapolis-Honeywell |

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## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Interface coordination (Little Joe II) | San Diego, California | 18 July | Cooper<br>Gatewood<br>Gately<br>Robinson | S&ID, NASA, and Convair |
| Crew systems | Houston, Texas | 18 July | Dewitt | S&ID, NASA |
| Coordination | Boston, Massachusetts | 18-20 July | Mayes | S&ID, NASA |
| Test operations and field analysis | El Centro, California | 18-19 July | Ellis<br>Young | S&ID, USN |
| Instrumental coordination for boilerplate testing | Houston, Texas | 18-20 July | Walker | S&ID, NASA |
| Pretest conference | Buffalo, New York | 18-20 July | McNary | S&ID, Cornell |
| Human factors | Cedar Rapids, Iowa | 19 July | Harman | S&ID, Collins |
| Coordination | Cambridge, Massachusetts | 19-20 July | Todd<br>Anaya | S&ID, NASA |
| Visual simulation technique discussion | Columbus, Ohio | 19-20 July | Smith | S&ID, NAA-Columbus |
| Liaison coordination | AMR | 19 July-1 August | Sheppard | S&ID, NASA |
| Wind tunnel test | Tullahoma, Tennessee | 20-28 July | Snowden | S&ID, NASA |
| Inverter bidder survey | Lima, Ohio<br><br>Broadbrook, Connecticut; Garland, Texas | 21-25 July | Miller | S&ID, Westinghouse; S&ID, Standard; S&ID, VARO |
| Isolation and revision study—bimonthly coordination | Baltimore, Maryland<br><br>New York, New York<br><br>Houston, Texas | 21-28 July | Smith | S&ID, Martin Marietta Corporation S&ID, Ferrand Optical and Computronics; S&ID, NASA |
| Comprehensive interfaces discussion | Cambridge, Massachusetts | 22-27 July | Martin<br>Zeitlin<br>Knobbee<br>Steiner | S&ID, MIT |
| IDWA test coordination | McGregor, Texas | 23-24 July | Magula<br>Spencer | Rocketdyne |
| Facilities coordination | Coco Beach, Florida | 23-24 July | Jeffers | S&ID, NASA |
| Fuel cell representative | Hartford, Connecticut | 23-27 July | Synder | S&ID, Pratt and Whitney |
| Biweekly power systems | Houston, Texas | 24-25 July | Synder<br>Nash<br>Champaign | S&ID, NASA |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Task to performance analysis and reentry simulation discussion | Minneapolis, Minnesota | 24-26 July | Blanchard<br>Traux | S&ID, Minneapolis-Honeywell |
| GSE checkout biweekly meeting | Houston, Texas | 25-26 July | Alpert<br>Triman<br>Scharzmann<br>Echmeir<br>Bouman<br>Russell | S&ID, NASA |
| Mechanical systems | Houston, Texas | 12 July | Champaign | S&ID, NASA |
| Engineering resident representative | Hartford, Connecticut | 26-29 July | Synder | S&ID, Pratt and Whitney |
| Controls and displays discussion | Cedar Rapids, Iowa | 26-30 July | Graham | S&ID, Collins |
| GSE meeting | Minneapolis, Minnesota | 26 July-4 August | McNerney<br>Gibson | S&ID, Minneapolis-Honeywell |
| Research and development coordination | Houston, Texas | 26 July-10 August | Cosmos | S&ID, NASA |
| PERT coordination | Houston, Texas | 28 July | Katz | S&ID, NASA |
| GSE cell fuel and design | Hartford, Connecticut | 29-31 July | Symons<br>Alpert | S&ID, Pratt and Whitney |
| Windows and space environment discussion | Dayton, Ohio | 29-31 July | Beam<br>Norris<br>Zims | S&ID, NASA, USAF |
| Survey processing | Orlando, Florida<br>Melbourne, Florida<br>Tappin Springs, Florida | 29 July-2 August | La Plante | S&ID, NASA |
| Minneapolis-Honeywell seminar | Minneapolis, Minnesota | 29 July-4 August | Secrist<br>Zeitten<br>Campbell<br>Purkey<br>Rowe<br>Garcia<br>Fritzinger | S&ID, Minneapolis-Honeywell |
| Facilities coordination | Houston, Texas (tentative) | 31 July-3 August | Harvey | S&ID, NASA |
| Impact tests | Hampton, Virginia | 31 July-8 August | Haas<br>Pahlen | S&ID, NASA |
| Test schedules | Houston, Texas | 31 July-1 August | Harvey<br>Pearce | S&ID, NASA |
| Redstone gantry modification | WSMR | 31 July-6 August | Cooper | S&ID, NASA |
| Liaison coordination | AMR | 31 July-14 August | Johnson | S&ID, NASA |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| AUGUST | | | | |
| Fuel cell interface meeting | Downey, California | 1 August | Nash<br>Mackay<br>Barnett<br>Day | S&ID, Pratt and Whitney |
| Gantry modification coordination | White Sands, New Mexico | 1-2 August | Kennedy | S&ID, NASA |
| Little Joe II - tower test discussion | White Sands, New Mexico | 1-2 August | Jacob | S&ID, NASA |
| Hydrogen engine review | West Palm Beach, Florida | 1-2 August | Field<br>Simkin | S&ID, Pratt and Whitney |
| General plan revision discussion | Houston, Texas | 1-3 August | SeLegue<br>Williamson | S&ID, NASA |
| Schedule test meeting | Houston, Texas | 1-3 August | Emrich | S&ID, NASA |
| Reentry simulation studies | Houston, Texas | 1-4 August | Klein | S&ID, NASA |
| Quality control plan discussion | Los Angeles, California | 3 August | Griffith-Jones<br>Martin | S&ID, AiResearch |
| Heat shield subcontractor meeting | Wilmington, Massachusetts | 3-10 August | Palmer<br>Conger<br>Hanifin<br>Jacob<br>Walkover<br>Nelson | S&ID, Avco |
| Computer complex briefing | Greenbelt, Maryland | 5 August | Schepak<br>Moorehouse | S&ID, NASA |
| Life systems integration meeting | Long Island, New York | 5-6 August | Wishon | S&ID, Alderson Research Laboratories |
| Navigation and guidance coordination | Cambridge, Massachusetts | 5-7 August | Phillips<br>Rose<br>Percy | S&ID, MIT |
| Wind tunnel tests | Mountain View, California | 5-15 August | Ufer<br>Sola | S&ID, Ames |
| Maintenance analysis procedure | Los Angeles, California | 6 August | Parker<br>Pollard<br>Wolfe | S&ID, AiResearch |
| Technical biweekly meeting | Houston, Texas | 6-7 August | Longino<br>Kronsberg | S&ID, NASA |
| Flight power systems meeting | Moffet Field, California | 6-7 August | Johnson | S&ID, Ames |
| Titan II propulsion development | Denver, Colorado | 6-8 August | Grycel<br>Henry<br>Robertson | S&ID, Martin-Denver |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Entry analysis coordination | Moffet Field, California | 6-8 August | Klein<br>Miller<br>Timothy | S&ID, NASA, ARC, MIT |
| Fuel cell and qualifications test meeting | Hartford, Connecticut | 6-9 August | Champaign<br>Nash | S&ID, Pratt and Whitney |
| Flight test panel meeting | Houston, Texas | 6-9 August | Gildea<br>Lowry<br>Dudek<br>Fouts | S&ID, NASA |
| Wind tunnel tests | Tullahoma, Tennessee | 7-9 August | Allen<br>Miller<br>Shurr | S&ID, AEDC |
| Vehicle coordination (Max "Q") | Houston, Texas | 7-9 August | Charnuck<br>Silverman | S&ID, NASA |
| Heat shield integration | Wilmington, Massachusetts | 7-9 August | Hanifin<br>Confer<br>Walkover | S&ID, Avco |
| GSE checkout meeting | Houston, Texas | 7-10 August | Triman<br>Morland | S&ID, NASA |
| Power system panel biweekly meeting | Houston, Texas | 7-10 August | Field<br>Peterson<br>Gibb<br>Jacob | S&ID, NASA |
| PS-1 tests | Moffet Field, California | 7-17 August | Cola | S&ID, Aerodynamics |
| Biweekly mechanical systems meeting | Houston, Texas | 8-9 August | Stevens<br>Korb<br>Nicholas<br>Opdyke | S&ID, NASA |
| Gemini mock-up review | El Centro, California | 8-10 August | Young | S&ID, NASA |
| Associate contractor coordination meeting | Cambridge, Massachusetts | 8-10 August | Stratton | S&ID, MIT |
| Life systems effort coordination | Houston, Texas<br>San Antonio, Texas | 8-12 August | Wells<br>Echmeir<br>Erickson | S&ID, NASA |
| Reference data procurement | San Diego, California | 9 August | Mundy | S&ID, Convair |
| Little Joe II coordination meeting | San Diego, California | 9-10 August | Gatewood<br>Gately<br>Robinson | S&ID, Convair |
| Heat transfer meeting | Davenport, Iowa | 9-12 August | Davis | S&ID, Bendix |
| GSE requirements and reliability meetings | Cambridge, Massachusetts | 9-15 | Morland<br>Russell<br>Triman<br>Fatton | S&ID, MIT |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Integration coordination | Houston, Texas | 9-24 August | Silverman | S&ID, NASA |
| Management coordination | Downey, California | 10 August | Todd | S&ID, NASA, MIT |
| Lunar excursion module simulation evaluation | Columbus, Ohio | 10-11 August | Pearce | S&ID, NAA-Columbus |
| Ballistic missile and space technology | Colorado Springs, Colorado | 10-17 August | Simkin | Symposium |
| Wind tunnel tests | Buffalo, New York | 10-20 August | Karydas | S&ID, Cornell |
| Checkout procedures | AMR | 12-16 August | Haight<br>Butler<br>Clauss | S&ID, NASA |
| Heat shield and ablation | Wilmington, Massachusetts | 12-17 August | Charbourne | S&ID, Avco |
| Quality test plan | Hartford, Connecticut | 12-17 August | Nash<br>Synder | S&ID, Pratt and Whitney |
| AIEE energy conversion conference | San Francisco, California | 12-17 August | Dutzi | Symposium |
| Training plan coordination | Cedar Rapids, Iowa | 12-18 August | Smith | S&ID, Collins |
| Field analysis test operations | El Centro, California | 13-14 August | Bielefeld<br>Ellis<br>Large<br>Young | S&ID, USN |
| Mechanical integration flight dynamics | Houston, Texas | 13-15 August | Gatewood | S&ID, NASA |
| Instrumentation and calibration discussion | Morristown, New Jersey | 13-15 August | Shelley<br>Schepak | S&ID, RCA-DEP |
| GSE and fuel cell meeting | Hartford, Connecticut | 13-15 August | Symons | S&ID, Pratt and Whitney |
| Biweekly crew systems meeting<br>Food effort discussion | Houston, Texas | 13-16 August | Dewitt<br>Hair<br>Brewer<br>Tarr | S&ID, NASA |
| Facilities coordination | AMR | 13-16 August | McKim | S&ID, NASA |
| Solar flare methods survey | Los Alamos, Albuquerque, New Mexico | 13-18 August | Pickney | S&ID, NASA |
| Test matters coordination | AMR Houston, Texas; Tulsa, Oklahoma | 13-19 August | Cranston | S&ID, NASA, NAA-Tulsa |
| Tower jettison motor plane | Tullahoma, Tennessee | 14-15 August | Bellamy | S&ID, AEDC |
| Biweekly technical panel meeting | Houston, Texas | 14-16 August | Gildea<br>Erickson<br>Smith | S&ID, NASA |
| Gemini mock-up review | St. Louis, Missouri | 14-16 August | Pyle | S&ID, NASA |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Biweekly technical meeting | Houston, Texas | 14-16 August | Gildea<br>Erickson<br>Smith | S&ID, NASA |
| Mechanical integration panel meeting | Houston, Texas | 14-17 August | Nicholas<br>White | S&ID, NASA |
| Equipment installation coordination | Minneapolis, Minnesota | 14-19 August | Peters<br>Mayers<br>Gasparre<br>Frost Jr. | S&ID, Minneapolis-Honeywell |
| TV review study | Cedar Rapids, Iowa | 15-16 August | Albinger<br>Pope | S&ID, NASA, Collins |
| Biweekly facilities coordination | Houston, Texas | 15-16 August | Erickson<br>Smith | S&ID, NASA |
| Tower and configuration control | White Sands, New Mexico<br>El Paso, Texas | 15-17 August | Dodds<br>Wolfe<br>Jacob<br>Leonard<br>Rogers<br>Dorian | S&ID, NASA |
| Wind tunnel test | Moffet Field, California | 15-29 August | Swenden | S&ID, Ames |
| Reaction control motors discussion | Houston, Texas | 16-17 August | Benner | S&ID, NASA |
| Test program review | Mountain View, California | 16 August | Woody<br>Barnett | S&ID, Ames |
| Theoretical and experimental investigation | Baltimore, Maryland | 17-20 August | Hackett | S&ID, Martin-Marietta Corporation |
| Bimonthly industrial support meeting | Huntsville, Alabama | 17-23 August | Cooper | S&ID, NASA |
| Pretest meeting | Hampton, Virginia;<br>Buffalo, New York | 17-24 August | Karfiol<br>Biss | S&ID, NASA, Cornell |
| Instrumentation coordination effort | Concord, California | 18-19 August | Dunham | S&ID, Systron Donner Corporation |
| GSE briefing and facilities coordination | Houston, Texas | 19-22 August | Triman<br>Eckmeir<br>Zeminick<br>Cooper | S&ID, NASA |
| Scoring methods, design and human factors conference | Columbus, Ohio;<br>Dayton, Ohio;<br>Houston, Texas | 19-24 August | Wolfe<br>Tilden | S&ID, NASA, USAF |
| Pretest conference<br><br>Shock tunnel coordination and aerojet testing | Newport News, Virginia;<br>Hampton, Virginia;<br>Wilmington, Massachusetts | 19-24 August | Sherr | S&ID, Avco |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Heat shield subcontractor coordination | Wilmington, Massachusetts | 19-24 August | Palmer | S&ID, MIT |
| Biweekly flight technology meeting | Houston, Texas | 20-21 August | Gershun<br>Lundgren | S&ID, NASA |
| Equipment and checkout preparation | Houston, Texas | 20-21 August | Nowicki<br>Jones | S&ID, NASA |
| Monthly progress review meeting | Cambridge, Massachusetts | 20-21 August | Morland<br>Beck | S&ID, NASA, MIT |
| MA-7 debriefing | Houston, Texas | 20-21 August | Robinson<br>Nelson<br>Maxwell<br>Antletz<br>Templeton<br>Lu<br>Rabideau | S&ID, NASA |
| Checkout meeting | Houston, Texas | 21-22 August | McNerney<br>Allen<br>Triman | S&ID, NASA |
| Boilerplate discussion | Houston, Texas | 21-22 August | Petrey<br>Hillberg | S&ID, NASA |
| Pretest conference | Hampton, Virginia | 21-23 August | Gillies<br>McNary | S&ID, NASA |
| Electrical systems design coordination | Houston, Texas | 21-28 August | Miller<br>Carey | S&ID, NASA |
| Little Joe II interface coordination | San Diego, California | 22-23 August | Gately<br>Milerson | S&ID, Convair |
| Biweekly mechanical systems meeting<br>General electric presentation | Houston, Texas | 22-24 August | Johnson<br>Stone<br>Sakai<br>Delast | S&ID, NASA, General Electric |
| Scoring methods briefing | Houston, Texas | 22-24 August | Traux | S&ID, NASA |
| Training equipment evaluation | Houston, Texas | 22-25 August | Smith | S&ID, NASA |
| Gemini heat shield | St. Louis, Missouri | 22-25 August | Nixon<br>Gershun<br>King<br>Morant | S&ID, McDonnell |
| Shock tub coordination | Boston, Massachusetts | 23-24 August | Biss | S&ID, Avco |
| R&D vehicles coordination | Houston, Texas | 23 August - 9 September | Leonard | S&ID, NASA |
| Fuel cell mounting coordination | Hartford, Connecticut | 24-29 August | Derbyshire<br>Anderson | S&ID, Pratt and Whitney |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Batteries, presentation | Houston, Texas | 26-27 August | Otzinger<br>Toomey<br>Reed | S&ID, NASA |
| Saturn-Apollo interfaces | Huntsville, Alabama | 26-30 August | Gaare<br>Robinson<br>Millenson | S&ID, NASA |
| Controls and displays presentation | Houston, Texas | 27-28 August | Martin<br>Cambell<br>Bagley<br>Curston<br>Brochmon<br>Wingo<br>Brewer | S&ID, NASA |
| GSE briefing | Tulsa, Oklahoma | 27-28 August | Asbury | S&ID, NASA |
| Configuration and design meeting | Houston, Texas | 27-28 August | | S&ID, NASA |
| Gas analyzer meeting | Houston, Texas | 27-28 August | Solitario | S&ID, NASA, AiResearch |
| Structural integration meeting | Huntsville, Alabama | 27-30 August | Warner<br>Novak | S&ID, NASA |
| Parachute drop tests | El Centro, California | 27-30 August | Ellis<br>Waudby<br>Bielefeld | S&ID, USN |
| TV review study | Cedar Rapids, Iowa | 28 August | Pope<br>Levine | S&ID, Collins |
| AIChE national meeting | Denver, Colorado | 28-29 August | Taylor | Symposium |
| GOSS meeting | Houston, Texas | 28-29 August | Pope<br>Longino | S&ID, NASA |
| Biweekly crew systems meeting | Houston, Texas | 28-30 August | DeWitt | S&ID, NASA |
| R&D instrumentation coordination | Houston, Texas | 28-30 August | Walker<br>Kuznicki | S&ID, NASA |
| Simulation meeting | Philadelphia, Pennsylvania | 28 August<br>3 September | Shiffman | S&ID, General Electric |
| Test site configuration negotiations | Las Cruces, New Mexico;<br>El Paso, Texas | 29-30 August | Jacob<br>Dorian<br>Rogers<br>Cooper<br>Kennedy | S&ID, NASA |
| Guidance and control biweekly systems meetings | Houston, Texas | 29-30 August | Kennedy<br>Jansen<br>Yee<br>Quebedeaux | S&ID, NASA |
| Leach tape coordination | Houston, Texas | 29-31 August | Bernhard | S&ID, NASA |

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## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Tower jettison motor and installation research discussion | Elkton, Maryland; Silver Springs, Maryland | 29 August - 3 September | Warme<br>Bergeren | S&ID, Thiokol |
| Heat shield meeting | Wilmington, Massachusetts | 30 August - 2 September | Gersham<br>Stone<br>Morant<br>Confer | S&ID, Avco |
| SEPTEMBER | | | | |
| American psychological association | St. Louis, Missouri | 1-4 September | Rabideau | Symposium |
| Parachute drop preparation | El Centro, California | 3-4 September | Ellis | S&ID, NAA-Northrop-Ventura, USN |
| Facilities negotiation | Houston, Texas | 4 September | Dieterle<br>Morant<br>Kerr | S&ID, NASA |
| Powers systems and mechanical biweekly meeting | Houston, Texas | 1-5 September | Johnson<br>Gibb<br>Hines<br>Burrey<br>Novack | S&ID, NASA |
| Analysis methodology discussion | Wright-Patterson Air Force Base | 1-6 September | Rabideau | S&ID, USAF |
| Honeycomb panel status meeting | Middleton, New York | 1-6 September | Confer | S&ID, Aeronca |
| Hypervelocity data presentation wind tunnel test | Mountain View, California | 4-6 September | Allen<br>Greenschlag<br>Schurr<br>Wiltse<br>Conetti | S&ID, NASA, Ames |
| Biweekly system training meeting and GSE coordination | Houston, Texas | 4-6 September | Finley<br>Lambert<br>Chase<br>Smith | S&ID, NASA |
| Joint laboratory meeting | Cedar Rapids, Iowa | 1-6 September | Moore | S&ID, Collins |
| Telemetry checkout and review | Houston, Texas | 1-7 September | Himmelberg | S&ID, NASA |
| Measurement and tooling meeting | Dayton, Ohio | 4-7 September | Barnett<br>Smith<br>Perry<br>Best | Symposium |
| Instrumentation liaison | Houston, Texas | 4-7 September | Barmore<br>Thurman | S&ID, NASA |
| Reliability studies and interface discussion | Cambridge, Massachusetts | 4-7 September | Jones<br>Meyers<br>Fatton | S&ID, MIT |



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Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Wind tunnel tests | Tullahoma, Tennessee | 4-15 September | Snowden | S&ID, NASA |
| Static pressure test | Mountain View, California | 5 September | Beeman<br>Henrich | S&ID, Ames |
| Plume impingement surface heating discussion | Tullahoma, Tennesse | 5-6 September | Piesik | S&ID, NASA |
| Flight technology panel meeting | Houston, Texas | 5-6 September | Dodds<br>Peterson<br>Johnson | S&ID, NASA |
| Site survey coordination | White Sands, New Mexico | 5-7 September | Becker<br>Doyle | S&ID, USN |
| Wind tunnel tests | Moffet Field, California | 5-8 September | Daileda | S&ID, USN |
| AMR liaison coordination | Coco Beach, Florida | 5-20 September | Gore | S&ID, NASA |
| Pre-qualification flight drop tests | El Centro, California | 5-29 September | Waudby<br>Duffy<br>Bielefield | S&ID, NAA-Northrup-Ventura |
| Computer and interface coordination | Boston, Massachusetts | 6-7 September | Whitehead | S&ID, MIT |
| Interface coordination | Houston, Texas | 6-21 September | Swany | S&ID, NASA |
| Propulsion engine review | Los Angeles, California | 7 September | Briggs | S&ID, Aerojet General |
| WSMR facilities (Little Joe II/Apollo) | San Diego, California | 7 September | Jacob | S&ID, Convair |
| Landing impact meeting | Phoenix, Arizona | 7-9 September | Stone | S&ID, Aviation Crash Injury |
| Interface coordination | San Diego, California | 7-10 September | Cooper<br>Kennedy<br>Bendees | S&ID, Convair |
| Monthly coordination | Cedar Rapids, Iowa | 8-18 September | Lee Rose<br>Meier<br>Covington<br>Zemenick<br>Hagelberg<br>Ridlon<br>Robinson<br>Albinger<br>Newman | S&ID, Collins |
| European TV techniques investigation | Geneva, Switzerland<br>Zurich, Switzerland | 8-20 September | Hart | S&ID |
| Radiation heat transfer | Houston, Texas | 9-11 September | Greenschlag | S&ID, NASA |
| Heat shield substructure coordination | Wilmington, Massachusetts | 9-14 September | Chadbourne | S&ID, Avco |
| Temporary engineering representation | Hartford, Connecticut | 9-16 September | Snyder | S&ID, Pratt and Whitney |

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## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Communications meeting | Houston, Texas | 10-11 September | Hayes<br>Atlas | S&ID, NASA |
| Interface meeting | San Diego, California | 10-11 September | Millenson<br>Robinson<br>Gately | S&ID, Convair |
| Electrical systems meeting | Houston, Texas | 10-11 September | Green<br>Page<br>Lambert<br>Elderkin | S&ID, NASA |
| Requirements coordination review | AMR | 10-12 September | Cranston | S&ID, NASA |
| Human impact testing | Columbus, Ohio | 10-12 September | Shelton | S&ID, NAA-Columbus |
| Mock-up coordination | Houston, Texas | 10-13 September | Zimmerman<br>Muramatsu | S&ID, NASA |
| Backup entry display | Houston, Texas | 10-13 September | Beeler | S&ID, NASA |
| Presidential briefing | Houston, Texas | 10-13 September | Muramatsu | S&ID, NASA |
| Environmental control systems coordination | Minneapolis, Minnesota | 10-14 September | Gibson<br>Phillips<br>McNerney<br>Percy<br>Jorgensen<br>Gasparre | S&ID, Minneapolis-Honeywell |
| Procedure and operations meeting | AMR | 10-14 September | Denman | S&ID, NASA |
| NASA request meeting | Houston, Texas | 11 September | Proctor | S&ID, NASA |
| Facilities survey | Huntington Park, California | 11 September | Butler | S&ID, Raymond Development |
| Field analysis meeting | Redlands, California | 11 September | Parker | S&ID, Lockheed |
| Crew systems meeting | Houston, Texas | 11-12 September | DeWitt | S&ID, NASA |
| Systems trainers conference | Houston, Texas | 11-13 September | Chase<br>Lambert<br>Smith<br>Elderkin | S&ID, NASA |
| Logistics data coordination | Los Angeles, California | 12 September | Parker<br>Harris | S&ID, AiResearch |
| Boilerplate cooling requirement and procedure discussion | Houston, Texas | 12-13 September | Reithmaier<br>Sheere | S&ID, NASA |
| Parachute drop preparation | El Centro, California | 12-13 September | Ellis | S&ID, NASA |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Site survey review and building requirement presentation and approval | El Paso, Texas | 12-13 September | Mundy | S&ID, NASA |
| Field maintenance problems | Cedar Rapids, Iowa | 12-14 September | Zemenick | S&ID, Collins |
| Displays and controls meeting (Resident representative) | Cambridge, Massachusetts | 12-14 September | Gregorek | S&ID, MIT |
| Computer equipment inspection | Ogden, Utah | 12-14 September | Hill | S&ID, USAF |
| Alternate couch design and tests discussion | Wright-Patterson Air Force Base | 13 September | Shelton | S&ID, NAA-Columbus, USAF |
| Requirements review | Houston, Texas | 13 September | Cranston | S&ID, NASA |
| Coordination meeting | Los Angeles, California | 13 September | Reilly | S&ID, AiResearch |
| Biweekly guidance and control meeting | Houston, Texas | 13-14 September | Kennedy<br>Martin<br>Zeitlin<br>Robins | S&ID, NASA |
| Thermal meeting | Minneapolis, Minnesota | 13-14 September | Lee Rose | S&ID, Minneapolis-Honeywell |
| Fuel cell and program review | Boston, Massachusetts<br>Hartford, Connecticut<br>Elkton, Maryland | 13-19 September | Nelson<br>Nash | S&ID, G.E., Pratt and Whitney, Thiokol |
| Document coordination | Tulsa, Oklahoma | 14 September | Cranston | S&ID, NAA-Tulsa |
| Communications meeting | Lexington, Massachusetts | 14-21 September | Werner | S&ID, MIT |
| Weight meeting | Houston, Texas | 16-17 September | Ryker | S&ID, NASA |
| Navigation and guidance telemetry meeting | Cambridge, Massachusetts | 16-18 September | Eckmeier<br>Allen<br>Whitehead<br>Steiner | S&ID, MIT |
| Launch and support facilities requirement (Little Joe II) | Las Cruces, New Mexico | 16-18 September | Jacob<br>Kennedy<br>Dorian<br>Cooper | S&ID, NASA |
| Aerospace medical association meeting | Las Vegas, Nevada | 16-20 September | Wells | Symposium |
| GSE checkout meeting | AMR Cambridge, Massachusetts | 16-21 September | Eckmeier | S&ID, NASA, MIT |
| Heat shield subcontractor coordination | Wilmington, Massachusetts | 16-21 September | Taylor | S&ID, Avco |
| Operations meeting | Tulsa, Oklahoma | 16-24 September | Martin | S&ID, NAA-Tulsa |

Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Biweekly crew support coordination | Houston, Texas | 24-26 September | Brewer<br>Tarr<br>Bowman<br>Steinmetz<br>Lauback | S&ID, NASA |
| Crew performance and problems discussion | St. Louis, Missouri | 24-26 September | Blanchard | S&ID, McDonell Aircraft |
| Field analysis cost reduction meeting | Cedar Rapids, Iowa<br>Minneapolis, Minnesota | 24-28 September | Hagelberg<br>Stady | S&ID, Collins<br>S&ID, Minneapolis-Honeywell |
| Negotiations meeting | Houston, Texas | 25-26 September | Paup<br>Pyle | S&ID, NASA |
| GOSS meeting | Houston, Texas | 25-26 September | Keihlo | S&ID, NASA |
| Crew systems meeting | Houston, Texas | 25-27 September | DeWitt | S&ID, NASA |
| Pressure suit coordination | Houston, Texas | 25-27 September | Brockman | S&ID, NASA |
| Mercury mission launch | AMR | 25-28 September | Cranston<br>Carter<br>Harvey | S&ID, NASA |
| Stabilization and control system meeting | Houston, Texas | 25-28 September | Kennedy<br>Levine<br>Zeitlin<br>Onteveros<br>Robins | S&ID, NASA |
| Interface meeting | AMR | 25-30 September | Robertson<br>Randall | S&ID, NASA |
| Impact test meeting | Hampton, Virginia | 25 September<br>16 October | Haas | S&ID, Langley Research Center |
| Pressure suit test procedures | Minneapolis, Minnesota | 26-27 September | Smith | S&ID, Minneapolis-Honeywell |
| Navigation and guidance stabilization and control meeting | Cambridge, Massachusetts | 26-27 September | Timothy | S&ID, MIT |
| Engineering coordination | Boulder, Colorado | 26-29 September | Hagluni<br>Davis<br>Bowman | S&ID, Beach Aircraft Corporation |
| Plan and changes meeting | Houston, Texas | 26-30 September | Griffith-Jones<br>Kleinhofer | S&ID, NASA |
| Docking simulation coordination | Columbus, Ohio | 26 September<br>6 October | Tutt | S&ID, NAA-Columbus |
| Technical briefing | Houston, Texas | 28 September | Kennedy | S&ID, NASA |
| Heat shield substructure and ablative material coordination | Wilmington, Massachusetts | 30 September<br>5 October | Chadbourne | S&ID, Avco |
| National space electronics and telemetry meeting | Miami Beach, Florida | 30 September<br>5 October | Pope | Symposium |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| NASA cost reduction meeting | Houston, Texas | 19-20 September | Osborn<br>Pyle | S&ID, NASA |
| Prelaunch simulations operation | Point Arguello, California | 19-23 September | Canin<br>Willen | S&ID, NASA |
| Scoring methods conference | Dayton, Ohio | 19-24 September | Wolfe | S&ID, NASA, USAF |
| Human factors analysis | Dayton, Ohio<br>Houston, Texas | 19-24 September | Tilden | S&ID, NASA, USAF |
| Parachute drop tests | El Centro, California | 19 September<br>10 October | Young<br>Ellis | S&ID, USN |
| PERT conference | Conoga Park, California | 20 September | Haeggstrom | S&ID, Rocketdyne |
| Wind tunnel test | Moffet Field, California | 20-21 September | Large | S&ID, Ames |
| Integration coordination | Houston, Texas | 20 September<br>5 October | Baum | S&ID, NASA |
| Mercury prelaunch mission | AMR | 21-28 September | Morris<br>Ackerman | S&ID, NASA |
| Human factors electronics meeting | St. Louis, Missouri | 22-25 September | Rabideau | S&ID, Electronic Industries Association |
| Command module equipment meeting | Houston, Texas | 23-24 September | Pope | S&ID, NASA |
| Support manuals coordination | Houston, Texas | 23-26 September | Fore | S&ID, NASA |
| Temporary technical representation | East Hartford, Connecticut | 23-27 September | Anderson | S&ID, Pratt and Whitney |
| Scale test meeting | Hampton, Virginia | 23-28 September | Pagaza | S&ID, Langley Research |
| Helium quality meeting | Edwards Air Force Base | 24 September | Duncan<br>Fazioli | S&ID, USAF |
| Support plan coordination | Los Angeles, California | 24 September | Guensche | S&ID, Northrop-Ventura |
| Crew safety systems panel meeting | Houston, Texas | 24 September | Jones<br>Garton | S&ID, NASA |
| Motion picture documentation coordination | Washington, D.C.<br>Hampton, Virginia | 24-25 September | Eggert | S&ID, NASA, Langley Research |
| Control systems discussion | Minneapolis, Minnesota | 24-26 September | Miller | S&ID, Minneapolis-Honeywell |
| Mission direction preparation | Houston, Texas | 24-26 September | Dimitruk | S&ID, NASA |

## Table A-1. Apollo Schedule of Meetings and Trips (Cont'd)

| Subject | Location | Date | S&ID Representative | Organization |
|---|---|---|---|---|
| Biweekly flight technology meeting | Houston, Texas | 17-18 September | Kinsler<br>Gershun<br>Hackell | S&ID, NASA |
| Heat shield review briefing | Houston, Texas | 17-20 September | Hanifin<br>Morant<br>Skene<br>Lowry | S&ID, NASA |
| Information procurement meeting | Great Neck, Long Island, New York | 17-20 September | Shelley | S&ID, Sperry Gyroscope |
| GOSS conference | Houston, Texas | 17-20 September | Strelow<br>Koos<br>Schepak | S&ID, NASA |
| GSE checkout meeting | AMR | 17-21 September | Triman<br>Day<br>Jacobson<br>Jorgensen<br>Dorrell<br>Shelly<br>McMillin<br>Pomykata | S&ID, NASA |
| Power systems meeting | Houston, Texas | 18-19 September | Wolfe<br>Pyle<br>Bellamy<br>Field | S&ID, NASA |
| Pretest conference | Mountain View, California | 18 September | Davey | S&ID, Ames |
| Interface coordination | Cambridge, Massachusetts | 18-20 September | Martin<br>Furber<br>Jansen<br>Lu | S&ID, MIT |
| Simulation coordination | Columbus, Ohio | 18-21 September | Porter | S&ID, NAA-Columbus |
| Monthly coordination meeting | Cedar Rapids, Iowa | 18-21 September | Frost<br>Glembotski<br>Berkemeyer<br>Anderson<br>Robinson<br>Chafee | S&ID, Collins |
| Wielding equipment tests | Chicago, Illinois | 18-21 September | Watts | S&ID, Sciaky Brothers |
| Checkout and calibration procedures review | Houston, Texas | 18-22 September | Barmore | S&ID, NASA |
| Radiation shielding coordination | Knoxville, Tennessee | 19 September | Clark | S&ID, Oak Ridge National Laboratory |
| Paraglider drop test | Edwards Air Force Base | 19 September | Pearce | S&ID, USAF |
| Aerojet subscale coordination | Manchester, Tennessee | 19-20 September | Field<br>Nakamura | S&ID, AEDC |